Physics 2014 (Outside Delhi) SET I

Time allowed : 3 hours **Maximum marks : 70**

1. **Using the concept of force between two infinitely long parallel current carrying conductors, define one ampere of current.** **[1]**

   Answer : One ampere is the current which when flowing through each of the two parallel uniform long linear conductors placed in free space at a distance of one metre from each other will attract or repel each other with a force of 2×10^{-7} N per metre of their length.

2. **To which part of the electromagnetic spectrum does a wave of frequency 5×10^{19} Hz belong ?** **[1]**

   Answer : The frequency 5×10^{19} Hz lies in the gamma region of the electromagnetic spectrum.

3. **What is the force between two small charges of 2×10^{-7}C and 3×10^{-7}C placed 30 cm apart in air?** **[1]**

Answer :

We know that, $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$

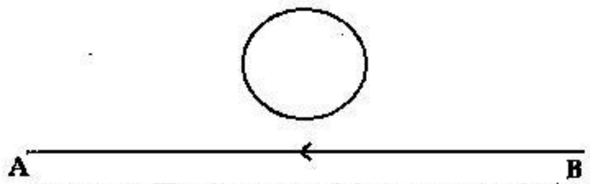
$$= 9 \times 10^9 \times \frac{(2\times10^{-7})(3\times10^{-7})}{(0.30)^2}$$

$$= 6 \times 10^{-3}\text{ N}$$

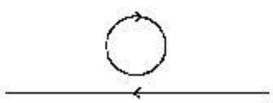
4. **Define intensity of radiation on the basis of photon picture of light. Write its S.I. unit. [1]**

Answer : The intensity of radiation can be defined as the energy associated with photons emitted from a unit surface area in unit time. Its S.I. unit is joule/metre^{2}second (J/m^{2}s).

5. **The electric current flowing in a wire in the direction from B to A is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown. [1]**



Answer : The direction of the current in the loop will be such as to oppose the decrease of this field (Lenz's Law).



6. **Why is it found experimentally difficult to detect neutrinos in nuclear β-decay ? [1]**

Answer : Neutrinos are difficult to detect experimentally in β-decay because these are uncharged particles with almost zero mass and also they interact weakly with matter.

7. **Why is the use of A.C. voltage preferred over D.C. voltage ? Give two reasons. [1]**

Answer : The use of A.C. voltage is preferred over the use of D.C. voltage because of the following reasons :

(i) The energy losses while transmission of A.C. voltage are very less as compared to D.C. voltage.

(ii) A.C. voltage can be controlled as required by using a transformer (*i.e.*, stepped up or stepped down).

8. **A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging or a diverging lens ? Give reason.[1]**

Answer : In this case the biconvex lens will behave as a diverging lens because the refractive index of water (1.33) is more than that of the material (1.25) of the lens.

9. **Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron ? [2]**

OR

Using Bohr's postulates of the atomic model, derive the expression for radius of n^{th} electron orbit. Hence obtain the expression for Bohr's radius.

Answer :

In a hydrogen atom, an electron having charge $-e$ revolves around the nucleus having charge $+e$ in a circular orbit of radius r.

Let,

F_c = Centripetal force required by the electron to move in circular orbit of radius r.

F_e = Electrostatic force of attraction between revolving electron and nucleus.

The electrostatic force of attraction (F_e) provides the necessary centripetal force,

$$F_c = F_e$$

$$\frac{mv^2}{r} = \frac{(e)(e)}{4\pi\varepsilon_0 r^2} \quad \text{...(i)}$$

K.E. of electron in the orbit,

$$\text{K.E.} = \frac{1}{2}mv^2$$

From equation (i),

$$\text{K.E.} = \frac{e^2}{8\pi\varepsilon_0 r}$$

Potential energy of electron in orbit,

$$\text{P.E.} = \frac{(e)(-e)}{4\pi\varepsilon_0 r} = \frac{-e^2}{4\pi\varepsilon_0 r}$$

$\therefore$ Total energy of electron in hydrogen atom

$$E = \text{E.K.} + \text{P.E.} = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$$

$$\text{E.K.} = -\frac{e^2}{8\pi\varepsilon_0 r}$$

Here, negative sign indicates that the revolving electron is bound to the positive nucleus.

OR

Suppose m be the mass of an electron and v_n be its speed in n^{th} orbit of radius r_n. From Rutherford model, the centripetal force for revolution is produced by electrostatic attraction between electron and nucleus.

$$\frac{mv_n^2}{r_n} = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n^2} \quad \text{...(i)}$$

From Bohr's postulate for quantization of angular momentum of n^{th} orbit.

$$mv_n r_n = \frac{nh}{2\pi} \Rightarrow v_n = \frac{nh}{2\pi m r_n}$$

Substituting this value in equation (i), we get

$$\frac{m}{r_n}\left[\frac{nh}{4\pi m r_n}\right]^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r_n^2}$$

or
$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m Z e^2}$$

For Bohr's radius $n = 1$,

$$r_1 = \frac{\varepsilon_0 h^2}{\pi m Z e^2}$$

This is the expression for Bohr's radius.

10. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor. [2]

Answer : Let 'q' be the charge on the charged capacitor.

Energy stored in it is,

$$U = \frac{q^2}{2C}$$

When another similar uncharged capacitor is connected, the net capacitance of the system is,

$$C' = 2C$$

The charge on the system is constant. So, the energy stored in the system now is,

$$U' = \frac{q^2}{2(C')^2}$$

$$\Rightarrow \quad U' = \frac{q^2}{2(2C)}$$

$$\Rightarrow \quad U' = \frac{q^2}{4C}$$

Thus, the required ratio is,

$$\frac{U'}{U} = \frac{\frac{q^2}{4C}}{\frac{q^2}{2C}}$$

$$\Rightarrow \quad \frac{U'}{U} = \frac{1}{2}$$

11. Considering the case of a parallel plate capacitor being charged, show how one is required to generalize Ampere's circuital law to include the term due to displacement current. [2]

Answer : Gauss' law states that the electric flux ϕ_E of a parallel plate capacitor having an area A, and a total charge Q is given by

$$\phi_E = EA = \frac{Q}{\varepsilon_0 A} \times A \qquad \left[\because E = \frac{Q}{A\varepsilon_0}\right]$$

$$= \frac{Q}{\varepsilon_0}$$

As the charge Q on the capacitor plates change with time, so current is given by

$$i = \frac{dQ}{dt}$$

$$\therefore \quad \frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

$$\Rightarrow \quad \varepsilon_0 \frac{d\phi_E}{dt} = \frac{dQ}{dt} = i$$

This is the missing term in Ampere's Circuital law.

So, the total current through the conductor is

i = Conduction current (i_c) + Displacement current (i_d)

$$i = i_c + \varepsilon_0 \frac{d\phi_E}{dt} \qquad \text{...(i)}$$

Ampere's circuital law states that,

$$\oint \vec{B}.\vec{dl} = \mu_0 i \qquad \text{...(ii)}$$

Putting equation (i) in (ii), we get

$$\oint \vec{B}.\vec{dl} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

This is the required generalized form of Ampere's circuital law.

12. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current 'I'. Using the plot, show how the emf of the cell and its internal resistance can be determined. [2]

Answer : The terminal voltage 'V' of the cell is given by

$$V = E - Ir$$

where E is the emf of the cell,

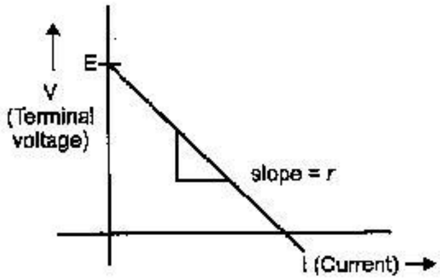
r is the internal resistance of the cell

and, I is the current through the circuit.

Comparing with the equation of a straight line $y = mx + c$, we get

$$y = V; x = I; m = -r; c = E$$

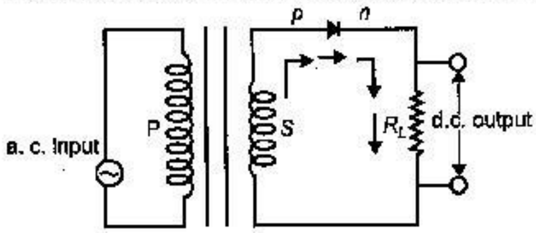
Graph showing variation of terminal voltage 'V' of the cell versus the current 'I'.



Emf of the cell = Intercept on V axis.
Internal resistance = slope of the line.

13. Explain, with the help of a circuit diagram, the working of a *p-n* junction diode as a half-wave rectifier. [2]

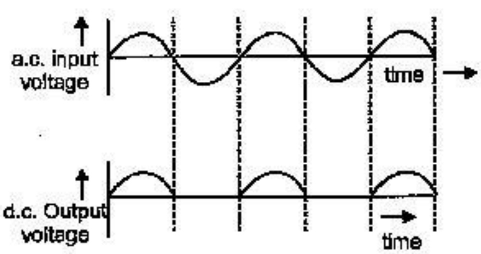
Answer : The circuit diagram for a *p-n* junction diode as a half wave rectifier is shown below :



Working : During the positive half cycle of the input a.c., the *p-n* junction is forward biased *i.e.,* the forward current flows from *p* to *n*. In the forward biasing, the diode provides a very low resistance and allows the current to flow. Thus, we get output across load.

During the negative half cycle of the input a.c., the *p-n* junction is reversed biased. In the reverse biasing, the diode provides a high resistance and hence a very small amount of current will flow through the diode which is of negligible amount. Thus no output is obtained across the load. During the next half cycle, output is again obtained as the junction diode gets forward biased. Thus, a half wave rectifier gives discontinuous and pulsating d.c. output across the load resistance.

The waveform of input and output is shown below :



14. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0 \times 10^{-7} m^2$ carrying a current of 1.5 A. Assume the density of conduction electrons to be $9 \times 10^{28} m^{-3}$. [2]

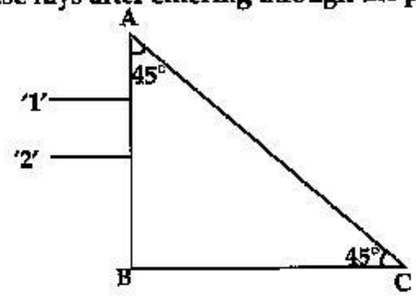
Answer : Since, drift velocity, $v_d = \frac{I}{nAq}$

where,
I is the current,
n is the charge density,
q is charge of the electron, and
A is cross-sectional area.

$$v_d = \frac{1.5}{9 \times 10^{28} \times 1.0 \times 10^{-7} \times 1.6 \times 10^{-19}}$$

$$v_d = 10.4 \times 10^{-4} \text{ m/s}$$

15. Two monochromatic rays of light are incident normally on the face AB of an isosceles right-angled prism ABC. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.35 and 1.45. Trace the path of these rays after entering through the prism. [2]



Answer : Critical angle of ray '1':

$$\sin(c_1) = \frac{1}{\mu_1} = \frac{1}{1.35}$$

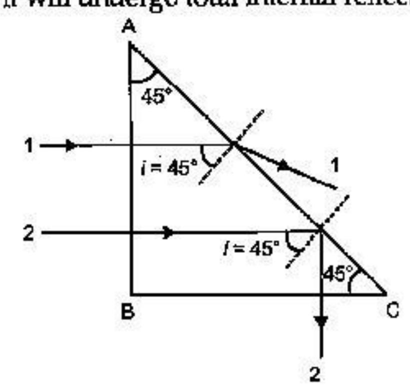
$$\Rightarrow \quad c_1 = \sin^{-1}\left(\frac{1}{1.35}\right) = 47.79°$$

Similarly, critical angle of ray '2':

$$\sin(c_2) = \frac{1}{\mu_2} = \frac{1}{1.45}$$

$$\Rightarrow \quad c_1 = \sin^{-1}\left(\frac{1}{1.45}\right) = 43.6°$$

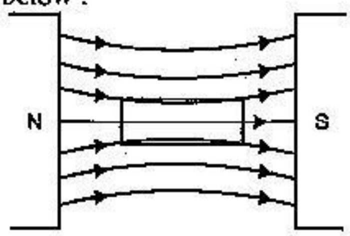
Ray '1' and '2' will fall on the side AC at an angle of incidence (i) of 45°. Critical angle of ray '1' is greater than i, so it will get refracted from the prism. Critical angle of ray '2' is less than that of i, so it will undergo total internal reflection.



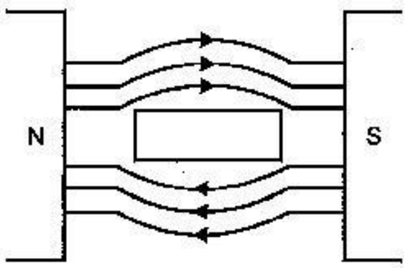
16. **Write the functions of the following in communication systems :**** **[2]**
(i) Transducer
(ii) Repeater

17. **Show diagrammatically the behaviour of magnetic field lines in the presence of (i) paramagnetic and (ii) diamagnetic substances. How does one explain this distinguishing feature ?** **[2]**

Answer : (i) The behaviour of magnetic field lines in the presence of a paramagnetic substance is shown below :



(ii) The behaviour of magnetic field lines in the presence of a diamagnetic substance is shown below :



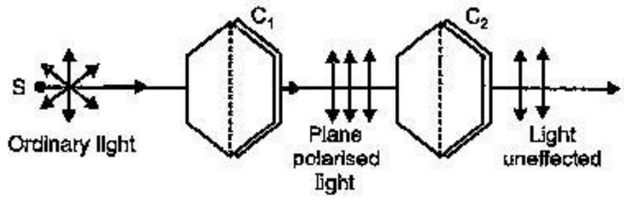
This distinguishing feature is because of the difference in their relative permeability. The relative permeability of diamagnetic substance is less than 1, so the magnetic lines of force do not prefer passing through the substance whereas the relative permeability of a paramagnetic substance is greater than 1, so the magnetic lines of force prefer passing through the substance.

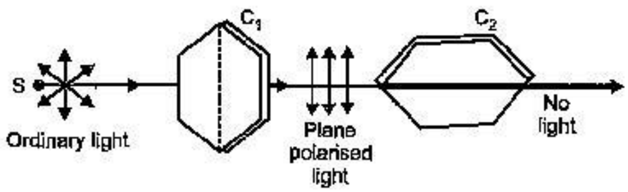
18. **Draw a circuit diagram of *n-p-n* transistor amplifier in CE configuration. Under what condition does the transistor act as an amplifier ?**** **[2]**

19. **(a) Using the phenomenon of polarization, show how transverse nature of light can be demonstrated.**
(b) Two polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Unpolarised light of intensity I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its pass axis makes an angle of 30° with that of P_1. Determine the intensity of light transmitted through P_1, P_2 and P_3. **[3]**

**Answers is not given due to change in the present syllabus.

Answer : (a) Suppose that an ordinary light is incident normally on a pair of crystals C_1 and C_2. When the incident ray of light passes through crystal C_1, it gets plane polarised in the direction perpendicular to the length of crystal. Now, we see that when the axis of two crystals are parallel, the intensity of the emerging light will be maximum. When the second crystal is placed perpendicular with respect to the first crystal, the intensity of light observed is zero. This is due to the electric field of the plane polarised light obtained from C_1 can vibrate only in one direction. Hence, when the axis of the crystal C_2 is perpendicular to its direction of vibration of electric field, it gets blocked. This shows the transverse nature of light.





(b) Intensity of light after falling on P_1,

$$I = \frac{I_0}{2}$$

Intensity of light after falling on P_3,

$$I' = I\cos^2(\theta) = \frac{I_0}{2}\cos^2(30°) = \frac{3I_0}{8}$$

$$\left[\because \cos 30° = \frac{\sqrt{3}}{2}\right]$$

Therefore, a light of intensity $\frac{3I_0}{8}$ will pass through the P_2, and the angle between P_3 and P_2 will be 60° because of the condition given in the question. Intensity of light after falling on P_2,

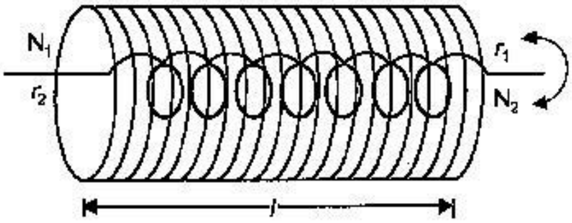
$$I'' = I'\cos^2 60°$$

$$I'' = \frac{3I_0}{8}\cos^2(60°) = \frac{3I_0}{32} \quad \left[\because \cos 60° = \frac{1}{2}\right]$$

20. **Define the term 'mutual inductance' between the two coils.**

Obtain the expression for mutual inductance of a pair of long coaxial solenoids each of length l and radii r_1 and r_2 ($r_2 >> r_1$). Total number of turns in the two solenoids are N_1 and N_2 respectively. **[3]**

Answer : Mutual inductance of two coils is equal to the e.m.f. induced in one coil when rate of change of current through the other coil is unity.



Mutual inductance of two co-axial solenoids :
Consider two long co-axial solenoid each of length l with number of turns N_1 and N_2 wound one over the other. Number of turns per unit length in solenoid, $n = \frac{N_1}{l}$. If I_1 is the current flowing in primary solenoid, the magnetic field produced within this solenoid.

$$B_1 = \frac{\mu_0 N_1 I_1}{l}$$

The flux linked with each turn of inner solenoid coil is $\phi_2 = B_1 A_2$, where A_2 is the cross-sectional area of inner solenoid. The total flux linkage with inner coil of N_2 turns.

$$\phi_2 = N_2 \phi_2$$
$$= N_2 B_1 A_2$$
$$= N_2 \left(\frac{\mu_0 N_1 I_1}{l}\right) A_2$$
$$= \frac{\mu_0 N_1 N_2 A_2 I_1}{l}$$

$$\text{Mutual Inductance, } M_{21} = \frac{\phi_2}{I_1} = \frac{\mu_0 N_1 N_2 A_2}{l}$$

If n_1 is number of turns per unit length of outer solenoid and r_2 is radius of inner solenoid, then

$$M = \mu_0 n_1 N_2 \pi r_2^2.$$

21. Answer the following : **[3]**

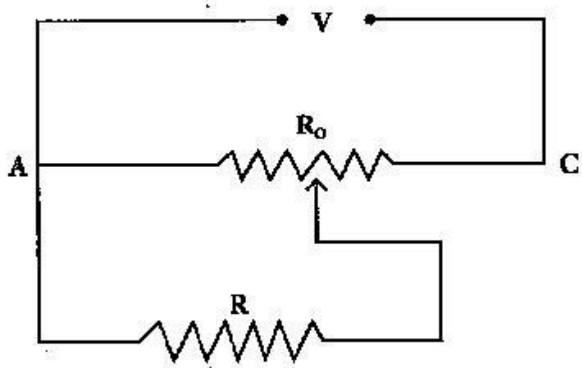
(a) Why are the connections between the resistors in a meter bridge made of thick copper strips ?

(b) Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire ?

(c) Which material is used for the meter bridge wire and why ?

OR

A resistance of R Ω draws current from a potentiometer as shown in the figure. The potentio meter has a total resistance R_0 Ω. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of the potentiometer.



Answer : (a) The connection between the resistors in a meter bridge is made of thick copper strips because the resistivity of a copper wire is very low. As, the connections are thick, so the area becomes large and the resistance of the wires becomes almost negligible.

(b) It is preferred to obtain the balance point in the middle of the meter bridge wire because it improves the sensitivity of the meter bridge.

(c) Constantan is used for meter bridge wire because its temperature coefficient of resistance is almost negligible due to which the resistance of the wire does not get affected on increasing temperature of the wire due to flow of current.

OR

As the slide is in the middle of the potentiometer so, only half of its resistance ($R_0/2$) will be in parallel with the resistance R. Hence, the total resistance (R_1) will be given by the following expression :

$$\frac{1}{R_1} = \frac{1}{R} + \frac{1}{(R_0/2)}$$

$$R_1 = \frac{R_0 R}{R_0 + 2R}$$

The total resistance between A and C is $R_1 + R_0/2$.

$\therefore$ The current flowing through the potentiometer will be

$$I = \frac{V}{R_1 + R_0/2} = \frac{2V}{2R_1 + R_0}$$

The voltage V_1 taken from the potentiometer will be the product of current I and resistance R_1.

$$V_1 = IR_1 = \left(\frac{2V}{2R_1 + R_0}\right) \times R_1$$

Substituting for R_1, we have

$$V_1 = \frac{2V}{2\left(\frac{R_0 \times R}{R_0 + 2R}\right) + R_0} \times \frac{R_0 R}{(R_0 + 2R)}$$

$$V_1 = \frac{2VR}{2R + R_0 + 2R}$$

or $$V_1 = \frac{2VR}{R_0 + 4R}$$

22. A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm apart from each other. A point object lies 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed. [3]

Answer : Let us first locate the image of the point object O formed by the convex lens.

Here : $u = -60$ cm and $f = 20$ cm

From the lens formula, we have :

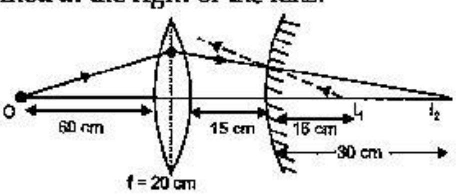
$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$$

$$= \frac{1}{20} + \frac{1}{-60} = \frac{3-1}{60} = \frac{2}{60} = \frac{1}{30}$$

$v = +30$ cm

The positive sign indicates that the image is formed at the right of the lens.



The image I_1 is formed behind the mirror and acts as a virtual oject for the mirror. The convex mirror forms the image I_2, whose distance from the mirror can be determined as :

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

Here, $$u = 15 \text{ cm}$$

and, $$f = \frac{R}{2} = 10 \text{ cm}$$

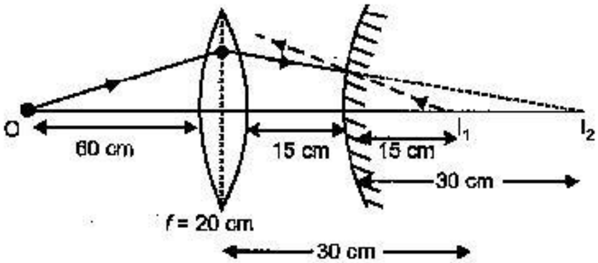
$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1}{10} - \frac{1}{15}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{3-2}{30} = \frac{1}{30}$$

$$\Rightarrow \quad v = 30 \text{ cm}$$

Hence, the final virtual image is formed at a distance of 30 cm from the convex mirror.



23. A voltage $V = V_0 \sin \omega t$ is applied to a series LCR circuit. Derive the expression for the average power dissipated over a cycle. Under what condition is (i) no power dissipated even though the current flows through the circuit, (ii) maximum power dissipated in the circuit ? [3]

Answer : Voltage $V = V_0 \sin \omega t$ is applied to a series LCR circuit.

Current is $\quad I = I_0 \sin(\omega t + \phi)$

$$I_0 = \frac{V_0}{Z}$$

$$\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)$$

Instantaneous power supplied by the source is

$$P = VI = (V_0 \sin \omega t) \times (I_0 \sin(\omega t + \phi))$$

$$= \frac{V_0 I_0}{2}[\cos\phi - \cos(2\omega t + \phi)]$$

The average power over a cycle is average of the two terms on the R.H.S. of the above equation.

The second term is time dependent, so, its average is zero.

So, $$P = \frac{V_0 I_0}{2}\cos\phi$$

$$= \frac{V_0 I_0}{\sqrt{2}\sqrt{2}}\cos\phi$$

$$= VI\cos\phi$$

$$P = I^2 Z \cos\phi$$

where, $\cos\phi$ is called the power factor.

Case 1.

For pure inductive circuit or pure capacitive circuit, the phase difference between current and voltage *i.e.*, ϕ is $\frac{\pi}{2}$.

$\therefore \quad \phi = \frac{\pi}{2}$

So $\quad \cos\phi = 0$

Therefore, no power is dissipated.

Case 2.

For power dissipated at resonance in an LCR circuit,

$$X_C - X_L = 0, \quad \phi = 0$$

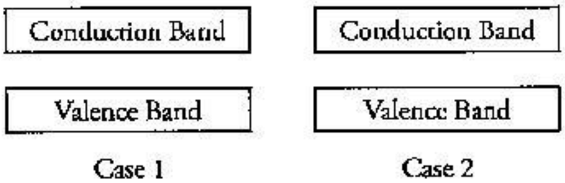
$$\therefore \quad \cos\phi = 1$$

So, maximum power is dissipated.

24. Write any two distinguishing features between conductors, semiconductors and insulators on the basis of energy band diagrams. [3]

Answer : Conductors :

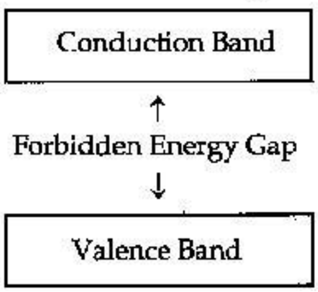
(i) In case of conductors, the valence band is completely filled and the conduction band can have two cases-either it is partially filled with an extremely small energy gap between the valence and conduction bands or it is empty, with the two bands overlapping each other as shown below :



(ii) Even when a small current is applied, conductors can conduct electricity.

Insulators :

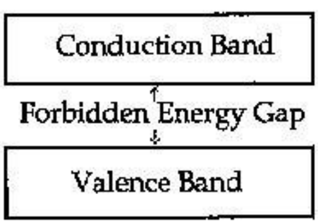
(i) In case of insulators, the energy gap between the conduction and valence bands is very large and the conduction band is practically empty.



(ii) When an electric field is applied to such kind of material, the electrons find hard to receive such a large amount of energy to reach the conduction band. Thus, the conduction band remains empty. That is why no current flows through insulators.

Semiconductors :

(i) In case of semiconductor, the energy band structure of semiconductors is similar to insulators, But in this case, the size of forbidden energy gap is quite smaller than that of the insulators.



****Answers is not given due to change in the present syllabus.**

(ii) When an electric field is applied to a semiconductor, the electrons in the valence band find it relatively easier to jump to the conduction band. So, the conductivity of semiconductors lies between the conductivity of conductors and insulators.

25. For the past some time, Aarti had been observing some erratic body movement, unsteadiness and lack of coordination in the activities of her sister Radha, who also used to complain of severe headache occasionally. Aarti suggested to her parents to get a medical check-up of Radha. The doctor thoroughly examined Radha and diagnosed that she has a brain tumour. [3]

(a) What, according to you, are the values displayed by Aarti?**

(b) How can radioisotopes help a doctor to diagnose brain tumour ?

Answer :

(b) A little amount of radioisotope like radioiodine is inserted into the body along with organic dyes which are absorbed strongly by the tumour tissue than the normal tissues. By detecting the emitted radiation, the radiologist get information about the size and location of the tumour.

26. Write two basic modes of communication. Explain the process of amplitude modulation. Draw a schematic sketch showing how amplitude modulated signal is obtained by superposing a modulating signal over a sinusoidal carrier wave. [3]**

27. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc., to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which used yellow light ? [3]

Answer : The de-Broglie wavelength of the electrons is given by :

$$\lambda = \frac{h}{\sqrt{2meV}}$$

Here,

m = mass of the electron $= 9.1 \times 10^{-31}$ kg

e = charge on the electron $= 1.6 \times 10^{-19}$ C

V = accelerating potential = 50 kV

h = Planck's constant $= 6.626 \times 10^{-34}$ Js

$$\Rightarrow \quad \lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2(9.1 \times 10^{-31})(1.6 \times 10^{-19})(50 \times 10^3)}}$$

$$\Rightarrow \quad \lambda = 0.0549 \text{Å}$$

Resolving power of a microscope, $R = \frac{2\mu \sin \theta}{\lambda}$

This formula shows that to enhance resolution, we have to use shorter wavelength and media with large indices of refraction.

For an electron microscope, μ is equal to 1 (vacuum).

For an electron microscope, the electrons are accelerated through a 60,000 V potential difference.

Thus, the wavelength of electrons is given by,

$$\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{60000}} = 0.05 \text{ Å}$$

As, λ is very little (roughly 10^{-5} times smaller) for electron microscope than an optical microscope which uses yellow light of wavelength (5700 Å to 5900 Å). So, the resolving power of electron microscope is about 10^5 greater than that of optical microscope.

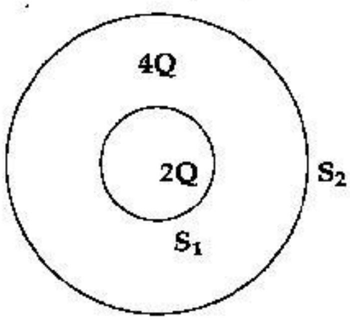
28. Draw a labelled diagram of Van de Graaff generator. State its working principle to show how by introducing a small charged sphere into a larger sphere, a large amount of charge can be transferred to the outer sphere. State the use of this machine and also point out its limitations. [5]

OR

(a) Deduce the expression for the torque acting on a dipole of dipole moment $\vec{p}$ in the presence of a uniform electric field $\vec{E}$.

(b) Consider two hollow concentric spheres, S_1 and S_2, enclosing charges 2Q and 4Q respectively as shown in the figure. (i) Find out the ratio of the electric flux through them. (ii) How will the electric flux through the sphere S_1 change if a medium of dielectric constant 'ε_r', 'ε_r' is introduced in the space inside S_1 in place of air?

Deduce the necessary expression.



Answer : Van de Graaff generator is a device used for building up high potential differences of the order of a few million volts.

Principle : The working of Van de Graaff generator is based on the following two electrostatic phenomena.

(i) Discharging action at sharp points (corona discharge) *i.e.,* electric discharge takes place in air or gases readily at the pointed ends of conductors.

(ii) If a charged conductor is brought into internal contact with a hollow conductor, all of its charge transfers to the hollow conductor, howsoever high the potential of the latter may be.

Construction : It has a big spherical conducting shell (S) kept over insulating pillars. A long narrow insulating belt is wound around two pulleys P_1 and P_2. B_1 and B_2 are two metal combs with sharp points. B_1 is known as spray comb and B_2 collecting comb.

Working : The spray comb provides positive potential by high tension source. The positive charge is sprayed on belt.

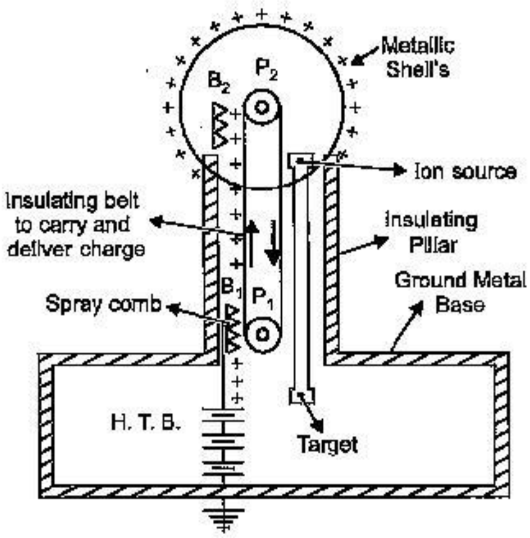
As belt moves and touches the sphere, a negative charge is induced on the sharp ends of collecting comb B_2 and similar positive charge is induced on the further end of B_2. This positive charge moves immediately to the outer surface of S, because of discharging action of sharp points of B_2, the positive charge on the belt is neutralized. The uncharged belt moves downwards and collects the positive charge from B_1, which is then collected by B_2. This process is repeated and the positive charge on S goes on accumulating. In this way, voltage differences of as much as 6 or 8 million volts (with respect to the ground) can be created.

Use : Van de Graaff generator is used to create high potential differences that are used to accelerate charged particles such as electrons, protons, ions, etc., used for nuclear reactions.

Limitations :

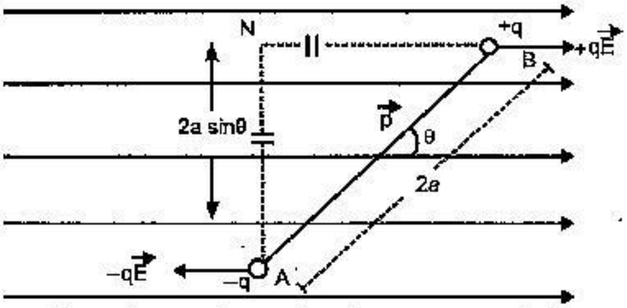
1. It is a series of combination that allows only one way for moving charge.

2. It can accelerate only the charged particles and not the uncharged particles.



OR

(a) Dipole in a Uniform External Field



Consider an electric dipole consisting of charges $-q$ and $+q$ and of length $2a$ placed in a uniform electric field $\vec{E}$ making an angle θ with electric field.

Force on charge $-q$ at A $= -q\vec{E}$ (opposite to $\vec{E}$)

Force on charge $+q$ at B $= +q\vec{E}$ (along $\vec{E}$)

Electric dipole is under the action of two equal and unlike parallel force, which give rise to a torque on the dipole.

τ = Force × Perpendicular distance between the two forces

$$\tau = qE(AN) = qE\,(2a\sin\theta)$$

$$\tau = pE\sin\theta \qquad [\because 2\,qa = P]$$

$$\vec{\tau} = \vec{p} \times \vec{E}$$

(b) (i) Charge enclosed by sphere $S_1 = 2Q$

By Gauss' law, electric flux through sphere S_1 is

$$\phi_1 = \frac{2Q}{\varepsilon_0}$$

Charge enclosed by sphere S_2 is

$$Q' = 2Q + 4Q = 6Q$$

Electric flux through sphere S_2 is

$$\therefore \quad \phi_2 = \frac{6Q}{\varepsilon_0}$$

The ratio of the electric flux is

$$\frac{\phi_1}{\phi_2} = \frac{\frac{2Q}{\varepsilon_0}}{\frac{6Q}{\varepsilon_0}} = \frac{2}{6} = \frac{1}{3}$$

(ii) For sphere S_1, the electric flux is

$$\phi' = \frac{2Q}{\varepsilon_r}$$

$$\therefore \quad \frac{\phi'}{\phi_1} = \frac{\varepsilon_0}{\varepsilon_r}$$

$$\Rightarrow \quad \phi' = \phi_1 \times \frac{\varepsilon_0}{\varepsilon_r}$$

$$\because \quad \varepsilon_r > \varepsilon_0$$

$$\therefore \quad \phi' < \phi_1$$

Therefore, the electric flux through the sphere S_1 decreases with the introduction of the dielectric inside it.

29. (a) In Young's double slit experiment, describe briefly how bright and dark fringes are obtained on the screen kept in front of a double slit. Hence obtain the expression for the fringe width.

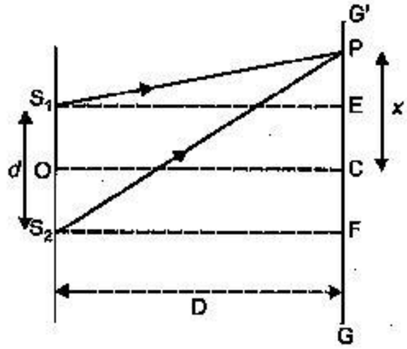
(b) The ratio of the intensities at minima to the maxima in the Young's double slit experiment is 9 : 25. Find the ratio of the widths of the two slits. [5]

OR

(a) Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

(b) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture 2×10^{-6} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of first maxima of the diffraction pattern obtained in the two cases.

Answer : (a) In Young's double slit experiment, the wave fronts from the two illuminated slits supere mpose on the screen. This results in formation of alternate bright and dark fringes because of constructive and destructive interference, respectively. The intensity of light is maximum at the centre C of the screen and it is called central maxima.



Let S_1 and S_2 be two slits separated by a distance d. GG' is the screen at a distance D from the slits S_1 and S_2. Both the slits are equidistant from point C. The intensity of light will be maximum at this point due to the path difference of the waves reaching this point will be zero.

At point P, the path difference between the rays coming from the slits S_1 and S_2 is $S_2P - S_1P$.

Now, $S_1S_2 = d$, $EF = d$, and $S_2F = D$

$\therefore$ In ΔS_2PF,

$$S_2P = [S_2F^2 + PF^2]^{\frac{1}{2}}$$

$$S_2P = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right]^{\frac{1}{2}}$$

$$= D\left[1 + \frac{\left(x + \frac{d}{2}\right)^2}{D^2}\right]^{\frac{1}{2}}$$

Similarly, in ΔS_1PE

$$S_1P = D\left[1 + \frac{\left(x - \frac{d}{2}\right)^2}{D^2}\right]^{\frac{1}{2}}$$

$$S_2P - S_1P = D\left[1 + \frac{\left(x + \frac{d}{2}\right)^2}{D^2}\right]^{\frac{1}{2}} - D\left[1 + \frac{\left(x - \frac{d}{2}\right)^2}{D^2}\right]^{\frac{1}{2}}$$

On expanding it binomially,

$$S_2P - S_1P = \frac{1}{2D}\left[4x \times \frac{d}{2}\right] = \frac{xd}{D}$$

For bright fringes (constructive interference), the path difference is an integral multiple of wavelengths, *i.e.*, path difference is $n\lambda$.

$$\therefore \quad n\lambda = \frac{xd}{D}$$

$$x = \frac{n\lambda D}{d}, \text{ where } n = 0, 1, 2, 3, 4, \ldots\ldots$$

For $n = 0$, $x_0 = 0$

$n = 1$, $x_1 = \frac{\lambda D}{d}$

$n = 2$, $x_2 = \frac{2\lambda D}{d}$

$n = 3$, $x_3 = \frac{3\lambda D}{d}$

$\vdots$

$n = n$, $x_n = \frac{n\lambda D}{d}$

The separation between the centres of two consecutive bright interference fringes is the width of a dark fringe.

$$\therefore \quad \boxed{\beta_1 = x_n - x_{n-1} = \frac{\lambda D}{d}}$$

Similarly, for dark fringes,

$$x_n = (2n - 1)\frac{\lambda D}{2d}$$

For $n = 1$, $x_1 = \frac{\lambda D}{2d}$

For $n = 2$, $x_2 = \frac{3\lambda D}{2d}$

The separation between the centres of two consecutive dark interference fringes is the width of a bright fringe.

$$\therefore \quad \boxed{\beta_2 = x_n - x_{n-1} = \frac{\lambda D}{d}}$$

$$\therefore \quad \beta_1 = \beta_2$$

All the bright and dark fringes are of equal width as $\beta_1 = \beta_2$

(b) Let w, a and I represent the slit width, amplitude and intensity respectively.

$$\frac{I_{min}}{I_{max}} = \frac{(a_1 - a_2)^2}{(a_1 + a_2)^2} = \frac{9}{25}$$

$$\frac{(a_1 - a_2)}{(a_1 + a_2)} = \frac{3}{5}$$

$$\frac{(a_1 - a_2) + (a_1 + a_2)}{(a_1 + a_2) - (a_1 - a_2)} = \frac{3 + 5}{5 - 3}$$

(By Componendo and dividendo)

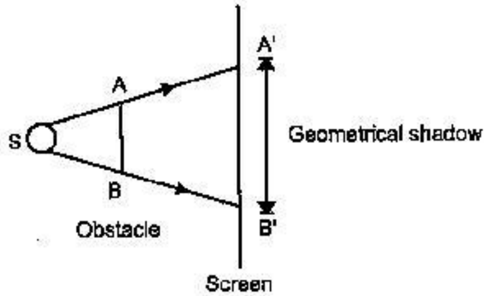
$$\frac{2a_1}{2a_2} = \frac{8}{2}$$

or $$\frac{a_1}{a_2} = \frac{4}{1}$$

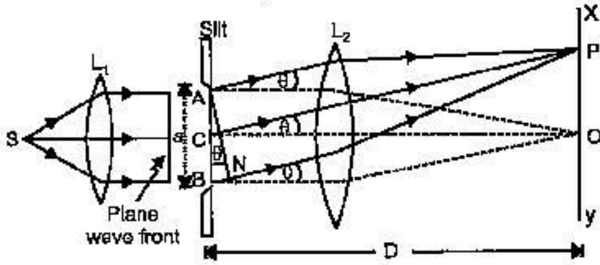
and $$\frac{w_1}{w_2} = \frac{(a_1)^2}{(a_2)^2} = \frac{16}{1}$$

OR

(a) The phenomenon of bending of light round the sharp corners of an obstacle and spreading into the regions of the geometrical shadow is called diffraction.



Expression for Fringe width



Consider a parallel light beam from a lens is incident on slit AB. As diffraction happens, the pattern is focussed on screen XY with the help of lens L_2. We will get a diffraction pattern that is a central maximum at the centre O flanked by a number of dark and bright fringes known as secondary maxima and minima.

Central Maximum : Each point on the plane wave front AB sends secondary wavelets in all directions. The waves from points equidistant from the centre C kept on the upper and lower half reach point O with zero path difference and so, reinforce each other, making maximum intensity at point O.

Positions and Widths of Secondary Maxima and Minima

Consider a point P on screen at which wavelets moving in a direction making angle θ with CO are brought to focus by the lens. The wavelets from points A and B will have a path difference similar to BN :

From the right-angled ΔANB, we have :

$$BN = AB \sin\theta$$

$$BN = a \sin\theta \qquad ...(i)$$

Suppose $BN = \lambda$ and $\theta = \theta_1$

Then, the above equation becomes

$$\lambda = a \sin\theta_1,$$

$$\sin\theta_1 = \frac{\lambda}{a} \qquad ...(ii)$$

Such a point on the screen will be the position of first secondary minimum,

If $BN = 2\lambda$ and $\theta = \theta_2$, then

$$\sin\theta_2 = \frac{2\lambda}{a} \qquad ...(iii)$$

Such a point on the screen will be the position of second secondary minimum.

In general, for n^{th} minimum at point P,

$$\sin\theta_n = \frac{n\lambda}{a} \qquad ...(iv)$$

If y_n is the distance of the n^{th} minimum from the centre of the screen, from right-angled ΔCOP, we have :

$$\tan\theta_n = \frac{OP}{CO}$$

$$\tan\theta_n = \frac{y_n}{D} \qquad ...(v)$$

In case θ_n is small, $\tan\theta_n \approx \sin\theta_n$

∴ Equations (iv) and (v) give

$$\frac{y_n}{D} = \frac{n\lambda}{a}$$

$$y_n = \frac{nD\lambda}{a}$$

Width of the secondary maximum,

$$\beta = y_n - y_{n-1} = \frac{nD\lambda}{a} - \frac{(n-1)D\lambda}{a}$$

$$\beta = \frac{D\lambda}{a} \qquad ...(vi)$$

∴ β is independent of n, all the secondary maxima are of the same width β.

If $BN = \frac{3\lambda}{2}$ and $\theta = \theta'$, from equation (i), we have :

$$\frac{3\lambda}{2} = a \sin\theta'_1$$

$$\sin\theta'_1 = \frac{3\lambda}{2}$$

In general, for the n^{th} maximum at point P,

$$\sin\theta'_n = \frac{(2n+1)\lambda}{2a} \qquad ...(vii)$$

If y'_n is the distance of n^{th} maximum from the centre of the screen, then the angular position of the maximum is given by

$$\tan\theta'_n = \frac{y'_n}{D} \qquad ...(viii)$$

In case θ'_n is small,

$\sin\theta'_n \approx \tan\theta'_n$

$$\therefore \quad y'_n = \frac{(2n+1)D\lambda}{2a} \qquad ..(viii)$$

Width of the secondary minimum,

$$\beta' = y'_n - y'_{n-1} = \frac{(2n+1)D\lambda}{2a} - \frac{(2n-1)D\lambda}{2a}$$

$$\beta' = \frac{D\lambda}{a} \quad ...(ix)$$

Since β' is independent of n, all the secondary minima are of the same width β'.

(b) For first maxima of the diffraction pattern we know

$$\sin\theta = \frac{3\lambda}{2a}$$

where a is aperture of slit.

For small value of θ, $\sin\theta \approx \tan\theta = \frac{y}{D}$

Where y is the distance of first minima from central line and D is the distance between the slit and the screen.

So, $$y = \frac{3\lambda}{2a}D$$

When $\lambda = 590$ nm, $a = 2 \times 10^{-6}$m, D = 1.5m

$$y_1 = \frac{3 \times 590 \times 10^{-9}}{2 \times 2 \times 10^{-6}} \times 1.5$$

$$y_1 = 0.66375 \text{ m}$$

When $\lambda = 596$ nm, $a = 2 \times 10^{-6}$, D = 1.5m

$$y_2 = \frac{3 \times 596 \times 10^{-9}}{2 \times 2 \times 10^{-6}} \times 1.5$$

$$y_2 = 0.6705 \text{ m}$$

Separation between the positions of first maxima $= y_2 - y_1 = 0.00675$ m or 6.75 mm

30. (a) Deduce an expression for the frequency of revolution of a charged particle in a magnetic field and show that it is independent of velocity or energy of the particle.

(b) Draw a schematic sketch of a cyclotron. Explain, giving the essential details of its construction, how it is used to accelerate the charged particles. [5]

OR

(a) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(b) Answer the following :

(i) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer.

(ii) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason.

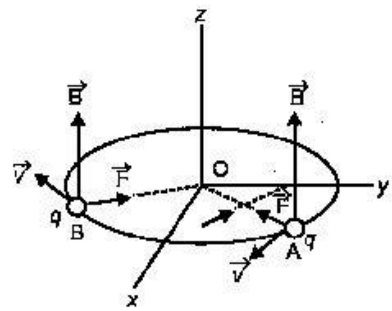
Answer : (a) When a charged particle having charge q moves inside a magnetic field $\vec{B}$ having velocity v, it experiences a force, which is given by :

$$\vec{F} = q(\vec{v} \times \vec{B})$$

Here,

$\vec{v}$ is perpendicular to $\vec{B}$,

$\vec{F}$ is the force on the charged particle which behaves as the centripetal force and make it to move in a circular path.



Let m be the mass of the charged particle and r be the radius of the circular path.

$$\therefore \quad q(\vec{v} \times \vec{B}) = \frac{mv^2}{r}$$

v and B are at right angles :

$$\therefore \quad qvB = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

Time period of circular motion of the charged particle can be calculated by,

$$T = \frac{2\pi r}{v}$$

$$= \frac{2\pi}{v}\frac{mv}{Bq}$$

$$T = \frac{2\pi m}{Bq}$$

$\therefore$ Angular frequency is

$$\omega = \frac{2\pi}{T}$$

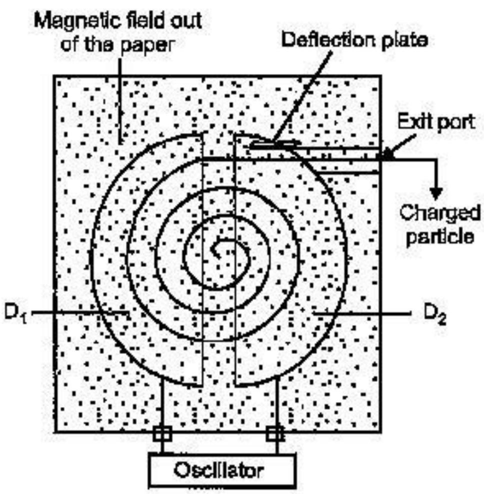
$$\therefore \quad \omega = \frac{Bq}{m}$$

Therefore, the frequency of the revolution of the charged particle is independent of the velocity or the energy of the particle.

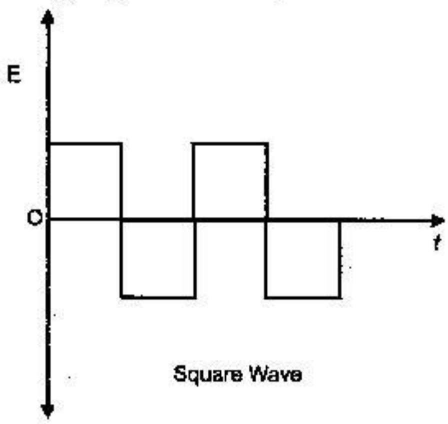
(b) The working principle of a cyclotron is that a charge particle can be accelerated to high energy by an oscillating electric field.

A cyclotron uses an electric field to accelerate charge particles across the gap between the two

D-shaped magnetic field regions. The magnetic field is perpendicular to the paths of the charged particles that makes them follow in circular paths within the two Ds. Each time the charged particles cross the Ds, it is accelerated by an alternating voltage. As its speed increases the radius of path of each particle also increases. So, the accelerated particles move in a spiral path to the other wall of the cyclotron.



Square wave electric fields are used to accelerate the charged particles in a cyclotron.

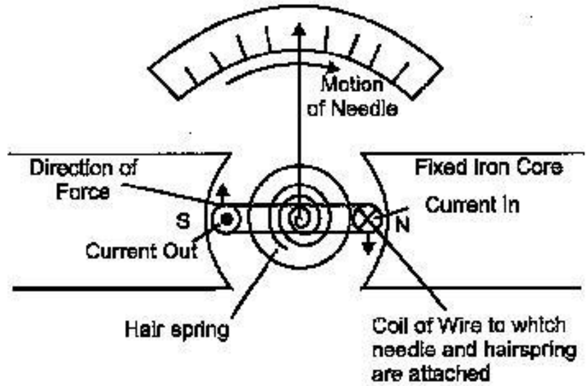


At the time the charge particle finishes its half circle, the accelerating electric field reverse so that it gets accelerated across the gap between the Ds.

The particle gets accelerated again and again, and its velocity increases. Therefore, a high kinetic energy is achieved.

OR

(a) Moving coil galvanometer : It is a device used for detecting and measuring small electric current.



Principle : The working is based upon the principle, when a current carrying coil suspended in a magnetic field experiences a torque.

Construction : It consists of a coil with a large number of turns of insulated copper wire wounded on a metallic frame. The coil is suspended by means of a phosphor bronze strip and a horse shoe magnet's NS surrounds it. The lower end of the coil is attached with a hair spring. The scale of the pointer is attached to the other end of the spring.

Working : When current is passed, the couple acts on it. Since the plane remains parallel to the magnetic field in all position of the coil, the force on the vertical arms always remains perpendicular to the place of the coil.

Let I = the current flowing through coil,

B = magnetic field supposed to be uniformed and always parallel to the coil, and

A = area of the coil.

Deflection acting on the coil is

$$\tau = NIBA \sin 90° = NIBA \qquad [\because \sin 90° = 1]$$

Due to the deflection torque, the coil rotates and suspended wire gets twisted. The suspension fiber experiences a restoring torque. If ϕ is angle through the coil rotates and k is the restoring torque per unit angular twist, then

Restoring torque, $\tau = k\phi$

In equilibrium, Deflection torque = Restoring torque

$$NIBA = k\phi$$

$$\phi = \left(\frac{NBA}{k}\right)I$$

$$\Rightarrow \quad \phi = \left(\frac{I}{G}\right)\cdot I$$

$$I = G\phi$$

where $G = \dfrac{k}{NBA}$ known as galvanometer constant.

$\therefore \quad \phi \propto I$

This provides a linear scale for the galvanometer.

(b) (i) When a soft iron core is used the magnetic field lines tend to crowd through the core. It is because, soft iron core is ferromagnetic in nature. As a result, the strength of the magnetic field due to the field magnet increases, which in turn increases the sensitivity of the galvanometer.

(ii) Current sensitivity of a galvanometer is defined as the deflection produced in the galvanometer when a unit current flows through it.

$$I_s = \frac{\theta}{I} = \frac{nBA}{K} \qquad ...(i)$$

Voltage sensitivity of a galvanometer is defined as the deflection produced in the galvanometer when a unit voltage is applied across two terminals.

$$V_s = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{nBA}{KR} = \frac{I_s}{R} \qquad ...(ii)$$

Where n = number of turns in the coil of galvanometer

B = Magnetic field around coil

A = Area of coil

K = restoring torque per unit twist

From equation (i) we can say that current sensitivity increases by increasing n, B, A and decreases by decreasing K.

From equation (ii) we can say that voltage sensitivity increases by increasing n, B, A and decreases by de reasing K, R.

In case of current sensitivity if we increases the no. of turns n its current sensitivity increases. Since resistance of galvanometer R also increases, voltage sensitivity remains same or unchanged.

Therefore increase in current sensitivity of galvanometer may not necessarily increase the voltage.

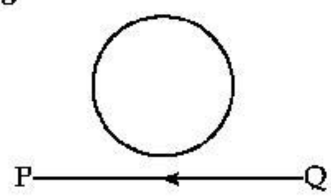
●●

Physics 2014 (Outside Delhi) SET II

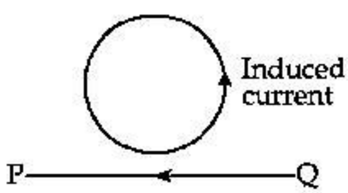
Time allowed : 3 hours **Maximum marks : 70**

Note : Except for the following questions, all the remaining questions have been asked in previous Set.

1. **A conducting loop is held above a current carrying wire 'PQ' as shown in the figure. Depict the direction of the current induced in the loop when the current in the wire PQ is constantly increasing.** [1]



Answer : Anticlockwise



4. **Why do the electrostatic field lines not form closed loops ?** [1]

Answer : The electrostatic field lines originate from positive charge and end at the negative charge. As the isolated positive and negative charge do exist, the electrostatic field lines do not form closed loops.

5. **A biconvex lens made of a transparent material of refractive index 1.5 is immersed in water of refractive index 1.33. Will the lens behave as a converging or a diverging lens ? Give reason.** [1]

Answer : The refractive index of material of lens (1.5) is greater than the refractive index of water (1.33). So, it will behave as a converging lens.

7. **To which part of the electromagnetic spectrum does a wave of frequency 3×10^{13} Hz belong ?** [2]

Answer : The frequency 3×10^{13} Hz belongs to infrared region of electromagnetic spectrum.

9. **Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $2.5 \times 10^{-7} m^2$ carrying a current of 1.8 A. Assume the density of conduction electrons to be 9×10^{28} m^{-3}.** [2]

Answer : Given : Current (I) = 1.8 A

Charge density $(n) = 9 \times 10^{28}\ m^{-3}$

Cross-section area $(A) = 2.5 \times 10^{-7}\ m^2$

Charge of electron $(q) = 1.6 \times 10^{-19}$ C

$$v_d = \frac{I}{nAq}.$$

$$= \frac{1.8}{9\times10^{28}\times2.5\times10^{-7}\times1.6\times10^{-19}}$$

$$= 0.0005\ m/s = 0.5\ mm\ s^{-1}$$

13. Write the functions of the following in communication systems :** **[3]**

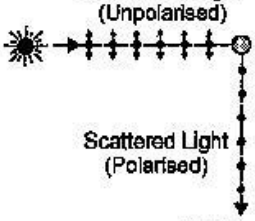
(i) Transmitter

(ii) Modulator

21. (a) Show with the help of a diagram, how unpolarised sunlight gets polarised due to scattering.

(b) Two polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Unpolarised light of intensity I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its pass axis makes an angle of 45° with that of P_1. Determine the intensity of light transmitted through P_1, P_2 and P_3. **[3]**

Answer : (a) The given figure shows, the incident sunlight is unpolarised. The dots stand for polarisation perpendicular to



the plane of the figure. The double arrows show polarisation in the plane of the figure. Under the influence of the electric field of the incident wave the electrons in the molecules acquire components of motion in both these directions. We have drawn an observer looking at 90° to the direction of the sun. Clearly, charges accelerating parallel to the double arrows do not radiate energy towards this observer since their acceleration has no transverse component. The radiation scattered by the molecule is therefore represented by dots. It is polarised perpendicular to the plane of the figure. This explains the polarisation of scattered light from the sky.

(b) As given in the question, the polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Also, P_3 is placed at an angle of 45° with respect to P_1.

Now, we have :

Intensity of light after falling on P_1, $I = I_0/2$

Intensity of light after falling on P_3,

$$I' = I\cos^2\theta = \frac{I_0}{2}\cos^2 45^\circ = \frac{I_0}{4}$$

Therefore, a light of intensity $I_0/4$ will pass through P_3 and the angle between P_3 and P_2 will be 45° because of the condition given in the question.

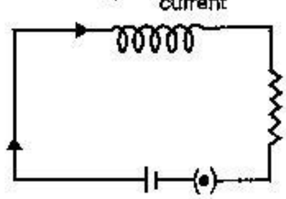
Intensity of light after falling on P_2,

$$I'' = I'\cos^2(\theta) = \frac{I_0}{4}\cos^2 45^\circ = \frac{I_0}{8}$$

22. Define the term self-inductance of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance L to build up a current I through it. **[3]**

Answer : The ratio of magnetic flux through the solenoid to the current passing through it is called self-inductance of a solenoid. It is given by

$$L = \frac{\phi}{I}$$



Energy stored in an inductor : When a current grows through an inductor, a back e.m.f. is set up which opposes the growth of current. So work needs to be done against back e.m.f. (e) in building up the current. This work done is stored as magnetic potential energy.

Let I be the current through the inductor L at any instant t. The current rises at the rate dI/dt.

So the induced e.m.f. is

$$e = \frac{-L\,dI}{dt}$$

The work done against induced e.m.f. in dt is

$$dW = P\,dt$$

$$= -e\,I\,dt \qquad [P = VI]$$

$$= \frac{L\,dI}{dt} I\,dt$$

$$= LI\,dI$$

For total work from 0 to I_0 current

$$W = \int dW$$

$$= \int_0^{I_0} LI\,dI$$

****Answers is not given due to change in the present syllabus.**

$$= L\left[\frac{I^2}{2}\right]_0^{I_0}$$

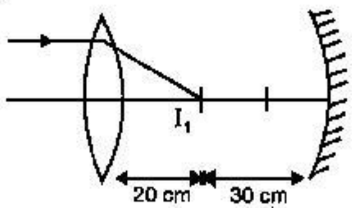
$$= \frac{1}{2}LI_0^2$$

Hence, this work done is stored as the magnetic potential energy U in the inductor

$$U = \frac{1}{2}LI^2$$

24. A convex lens of focal length 20 cm is placed coaxially with a concave mirror of focal length 10 cm at a distance of 50 cm apart from each other. A beam of light coming parallel to the principal axis is incident on the convex lens. Find the position of the final image formed by this combination. Draw the ray diagram showing the formation of the image. [5]

Answer : The beam incident on lens L is parallel to principal axis. Hence the lens forms an image I_1 at its focus. *i.e.*, at a distance OI_1 (= 20 cm) from the lens.



The image I_1 is formed in front of the mirror and hence, acts as a real source for the mirror. The concave mirror forms the image I_2, whose distance from the mirror can be calculated as;

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

Here : $u = -30$ cm, and $f = -10$ cm

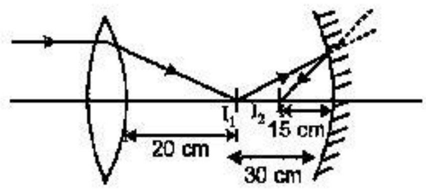
$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$\Rightarrow \quad \frac{1}{v} = -\frac{1}{10} + \frac{1}{30}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1-3}{30} = -\frac{2}{30}$$

$$\Rightarrow \quad v = -15 \text{ cm}$$

Hence, the final image is formed at a distance of 15 cm from the concave mirror, as shown in the following figure.



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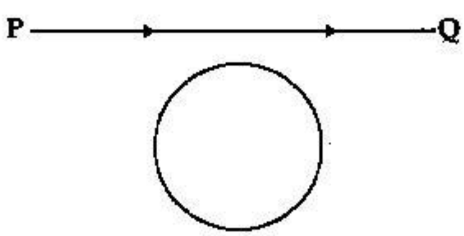
Physics 2014 (Outside Delhi) SET III

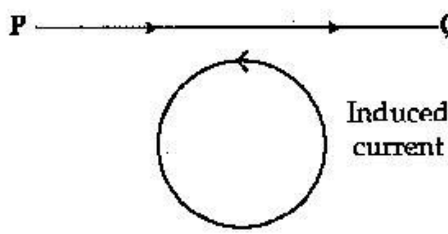
Time allowed : 3 hours **Maximum marks : 70**

> **Note : Except for the following questions, all the remaining questions have been asked in previous Sets.**

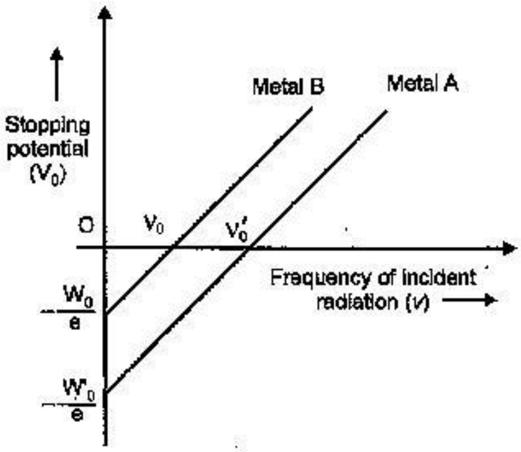
1. A conducting loop is held below a current carrying wire PQ as shown. Predict the direction of the induced current in the loop when the current in the wire is constantly increasing. [1]



Answer : Anticlockwise direction



2. The graph shows variation of stopping potential V_0 versus frequency of incident radiation ν for two photosensitive metals A and B. Which of the two metals has higher threshold frequency and why ? [1]



Answer : Metal A has higher threshold frequency because from the graph it is clear that the minimum frequency required to start photoemission is more in A than that of B.

5. **Why do the electric field lines never cross each other ? [1]**

Answer : At any point, if electric field lines cross each other than two tangents can be drawn, it means at that point there are two directions of electric field, which is impossible.

6. **To which part of the electromagnetic spectrum does a wave of frequency 5×10^{11} Hz belong ? [2]**

Answer : A wave of frequency 5×10^{11} Hz will belong to the microwaves of electromagnetic spectrum.

10. **Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $2.5 \times 10^{-7} m^2$ carrying a current of 2.7 A. Assume the density of conduction electrons to be 9×10^{28} m^{-3}. [2]**

Answer : We know that drift velocity, $v_d = \frac{I}{nAq}$

Where I is the current, n is charge density, q is charge of electron and A is cross-sectional area.

$$v_d = \frac{2.7}{9 \times 10^{28} \times 2.5 \times 10^{-7} \times 1.6 \times 10^{-19}}$$

$$v_d = 7.5 \times 10^{-4} \text{ m/s}$$

or $$v_d = 0.75 \text{ mm s}^{-1}$$

This is the required average drift velocity.

18. **Write the functions of the following in communication systems :** [3]**

(i) Receiver

(ii) Demodulator

19. **A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm from each other. A point object placed 40 cm in front of the convex lens. Find the position of the image formed by this combination. Draw a ray diagram to show the formation. [3]**

Answer : Given, 4 = –40 cm and, f = 20 cm

From the lens formula, we have :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

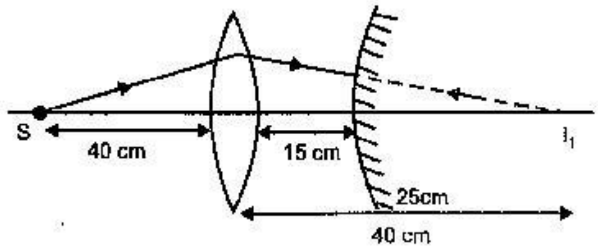
$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f} + \frac{1}{u}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1}{20} + \frac{1}{(-40)}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{2-1}{40} = \frac{1}{40}$$

$$\Rightarrow \quad v = 40 \text{ cm}$$

The positive sign describes that the image is formed to the right of the lens.



The image I_1 is formed behind the mirror and thus acts as a virtual source for the mirror. The convex mirror forms the image I_2, whose distance from the mirror is given by :

$$\frac{1}{v} + \frac{1}{v} = \frac{1}{f}$$

Here : u = 25 cm

$$f = \frac{R}{2} = 10 \text{ cm}$$

$$\frac{1}{v} - \frac{1}{v} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

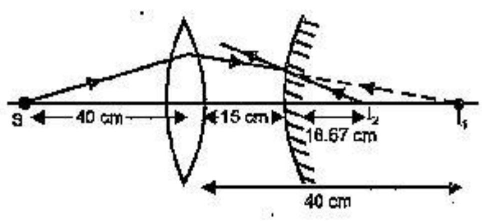
$$\Rightarrow \quad \frac{1}{v} = \frac{1}{10} - \frac{1}{25}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{5-2}{50} = \frac{3}{50}$$

$$\Rightarrow \quad v = +16.67 \text{ cm}$$

Hence, the final image is formed at a distance of 16.67 cm behind the convex mirror.

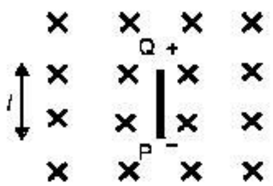
**Answers is not given due to change in the present syllabus.



25. (a) A rod of length 'l' is moved horizontally with a uniform velocity 'v' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.

(b) How does one understand this motional emf by involving the Lorentz force acting on the free charge carriers of the conductor? Explain. [5]

Answer : (a) Consider a rod PQ of length l, moving in a magnetic field $\vec{B}$ with a constant velocity $\vec{v}$. The length of the rod is perpendicular to the magnetic field and also the velocity is perpendicular to both the rod and field. The free electrons of the rod also move at this velocity $\vec{v}$ because of which it experiences a magnetic force.



$$\vec{F}_b = q\vec{v} \times \vec{B}$$

This force is towards Q to P.

Thus, the free electrons will move towards P and positive charge will appears at Q. An electrostatic field E is developed within the wire from Q to P. This field exerts a force.

$$\vec{F}_e = q\vec{E}$$

on each free electron. The charge keeps on gathering until

$$\vec{F}_b = \vec{F}_e$$

$$\Rightarrow \quad \left|q\vec{v} \times \vec{B}\right| = \left|q\vec{E}\right|$$

$$vB = E$$

After this, resultant force on the free electrons of the wire PQ becomes zero. The potential difference between the ends Q and P is given by,

$$V = El = vBl$$

Thus, the potential difference is maintained by the magnetic force on the moving free electron and hence, produces an emf, $e = Bvl$

(b) Lorentz force acting on a charge q which is moving with a speed v in a (normal) uniform magnetic field B, is Bqv.

All the charges will experience the same force.

Work done to move the charge from P to Q,

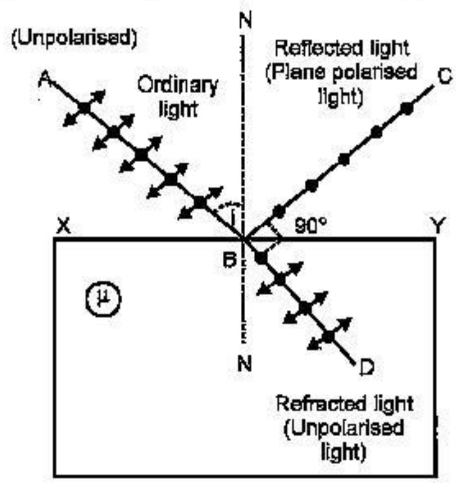
$$W = Bqv \times l$$

$$\therefore \quad e = \frac{W}{q} = \frac{Bqvl}{q} = Blv$$

26. (a) Show, giving via suitable diagram, how unpolarized light can be polarised by reflection.

(b) Two polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Unpolarised light of intensity I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its pass axis makes an angle of 60° with that of P_1. Determine the intensity of light transmitted through P_1, P_2 and P_3. [5]

Answer : (a) On reflection from a transparent medium a normal light beam becomes partially polarised. As the angle of incidence gets higher, the degree of polarization gets higher.



The reflected light beam becomes fully polarised at a certain angle. This angle of incidence is known as polarizing angle (p).

At the interface of a refracting medium when light is incident at polarizing angle, the refractive index of the medium is similar to the tangent of the polarizing angle.

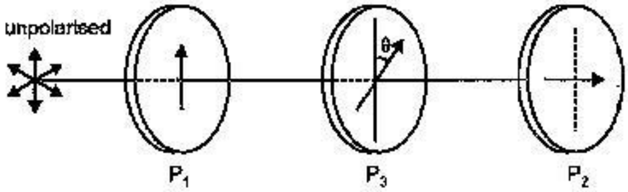
$$\mu = \tan p$$

where

$\mu \rightarrow$ Refractive index of the refracting medium

$p \rightarrow$ Polarising angle

(b) As given, the polaroid P_1 and P_2 are placed with their axes perpendicular to each other and polaroid P_3 placed at 60° with respect to P_1.



Therefore,

Intensity of light after falling on first polaroid P_1,

$$I = \frac{I_0}{2}$$

Intensity of light after falling on third polaroid P_3,

$$I' = I\cos^2(\theta) = \frac{I_0}{2}\cos^2(60°) = \frac{I_0}{8}$$

Therefore, the intensity $\frac{I_0}{8}$ will pass through the P_3 and angle between P_3 and P_2 is 30°. Because of the condition given in the question,

Intensity of light after falling on second polaroid P_2,

$$I'' = I'\cos^2\theta$$

$$= I''\cos^2 30° = \frac{3I_0}{32}$$

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Physics 2014 (Delhi) SET I

Time allowed : 3 hours **Maximum marks : 70**

1. Define the term 'mobility' of charge carriers in a conductor. write its S.I. unit. [1]

Answer : Mobility of charge carriers in a conductor is defined as the magnitude of their drift velocity per unit applied electric field.

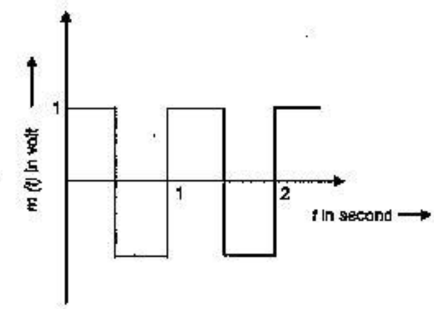
Mobility, μ = Drift of electric field

$$\mu = \frac{v_d}{E}$$

S.I. unit of mobility is $m^2V^{-1}s^{-1}$.

2. The carrier wave is given by C(*t*) = 2 sin (8π*t*) volt.

The modulating signal is a square wave as shown. Find modulation index. [1]**



3. For any charge configuration, equipotential surface through a point is normal to the electric field. Justify. [1]

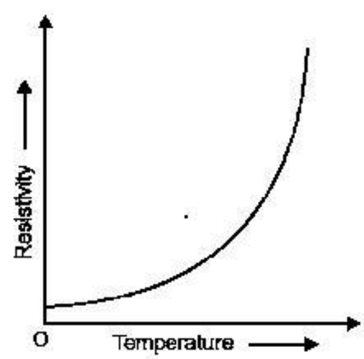
Answer : If the electric field were not normal to equipotential surface, it would have non-zero component along the surface. To move a charge against this component, work would have to be done. But no work is needed to move a test charge on an equipotential surface. Hence electric field must be normal to the equipotential surface at every point.

4. Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why ? [1]

Answer : Glass bob will reach the ground earlier than the metallic bob. As the metallic bob falls, it intercepts earth's magnetic field and induced currents are set up in it which oppose its downward motion. But no such currents are induced in the glass bob.

5. Show variation of resistivity of copper as a function of temperature in a graph. [1]

Answer : The variation of resistivity of copper with temperature is parabolic in nature. This is shown in the following graph :

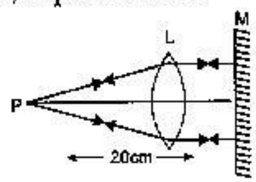


6. A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of this combination has its image

**Answers is not given due to change in the present syllabus.

coinciding with itself. What is the focal length of the lens ? **[2]**

Answer : The figure shows a convex lens L placed in contact with a plane mirror M. P is the point object, kept in front of



this combination at a distance of 20 cm, from it. As the image coincides with itself, the rays from the object, after refraction from lens, should fall normally on the mirror M, so that they retrace their path. For this, the rays from P, after refraction from the lens must form a parallel beam perpendicular to M. For clarity, M has been shown at a small distance from L (in diagram). As the rays from P, form a parallel beam after refraction, P must be at the focus of the lens. Hence, the focal length of the lens is 20 cm.

7. **Write the expression, in a vector form, for the Lorentz magnetic force $\vec{F}$ due to a charge moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. What is the direction of the magnetic force ?** **[2]**

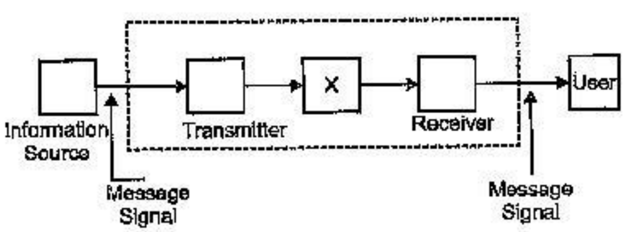
Answer : The Lorentz magnetic force is given by the following relation :

$$\vec{F} = q(\vec{v} \times \vec{B})$$

Here q, is the magnitude of the moving charge.

The direction of the magnetic force is perpendicular to the plane containing the velocity vector $\vec{v}$ and the magnetic field vector $\vec{B}$.

8. **The figure given below shows the block diagram of a generalized communication system. Identify the element labelled 'X' and write its function.**** **[2]**



9. **Out of the two magnetic materials, 'A' has relative permeability slightly greater than unity while 'B' has less than unity. Identify the nature of the materials 'A' and 'B'. Will their susceptibilities be positive or negative?** **[2]**

Answer : For a paramagnetic material, the relative permeability lies between $1 < \mu r < 1 + \varepsilon$ and its susceptibility lies between $0 < \chi < \varepsilon$.

Hence, 'A' is a paramagnetic material and its susceptibility is positive. This is because its relative permeability is slightly greater than unity. For a diamagnetic material, the relative permeability lies between $0 \le \mu_r < 1$ and its susceptibility lies between $-1 < \chi < 0$. Hence, 'B' is a diamagnetic material and its susceptibility is negative. This is because its relative permeability is less than unity.

Here μ_r and χ refer to the relative permeability and susceptibility.

10. **Given a uniform electric field $\vec{E} = 5 \times 10^3 \hat{i}$ N/C find the flux of this field through a square of 10 cm on a side whose plane is parallel to the YZ plane. What would be the flux through the same square if the plane makes a 30° angle with the X-axis ?** **[2]**

Answer : When the plane is parallel to the Y-Z plane :

Electric flux, $\phi = EA$

Here, $E = 5 \times 10^3 \hat{i}$ N/C

$A = 10 \text{ cm}^2 \hat{i} = 10^{-2} \hat{i} \text{ m}^2 = 10^{-2} \hat{i} \text{ m}^2$

$\phi = 5 \times 10^3 \hat{i} \cdot 10^{-2} \hat{i}$

$\Rightarrow \quad \phi = 50$ weber or Nm^2C^{-1}

When the plane makes a 30° angle with the X-axis, the area vector makes 60° with the X-axis.

$\phi = \vec{E} \cdot \vec{A}$

$\Rightarrow \quad \phi = EA \cos \theta$

$\Rightarrow \quad \phi = 5 \times 10^3 \cdot 10^{-2} \cos 60^\circ$

$\Rightarrow \quad \phi = \frac{50}{2}$

$\Rightarrow \quad \phi = 25$ weber or Nm^2C^{-1}

11. **For a single slit of width a, the first minimum of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of $\frac{\lambda}{a}$. At the same angle of $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance a. Explain.** **[3]**

**Answers is not given due to change in the present syllabus.

Answer : When a single slit is used, the interference pattern is due to the diffraction phenomenon. In case of diffraction from a single slit of width a using monochromatic light of wavelength λ, the first minimum of the interference pattern occurs at an angle θ_1, which is given by

$$\sin\theta_1 = \frac{\lambda}{a}$$

Since λ is very small, θ_1 will also be very small.

$$\therefore \quad \theta_1 \approx \sin\theta_1 = \frac{\lambda}{a} \quad ...(i)$$

In case of interference from two narrow slits separated by a distance a using monochromatic light of wavelength λ, the first maximum occurs at a distance y_1 from the centre of the screen, which is given by.

$$y_1 = \frac{D\lambda}{a}$$

Here, D is the distance of the screen from the centre of the slits.

If the first maximum occurs at an angle θ_1', then

$$\tan\theta_1' = \frac{y_1}{D} = \frac{\lambda}{a}$$

Again as λ is very small, θ_1' will also be very small.

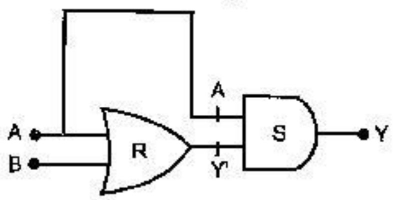
$$\therefore \quad \tan\theta_1' \approx = \theta_1' = \frac{\lambda}{a} \quad ...(ii)$$

From the equations (i) and (ii), we have

$$\theta_1 = \theta_1' = \frac{\lambda}{a}$$

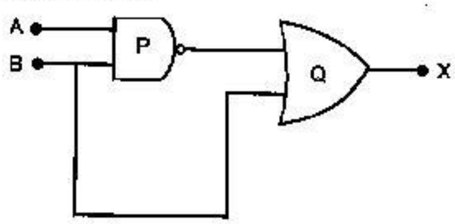
Hence, it proves the result.

12. Write the truth table for the combination of the gates shown. Name the gates used.** **[3]**



OR

Identify the logic gates marked 'P' and 'Q' in the given circuit. Write the truth table for the combination.**

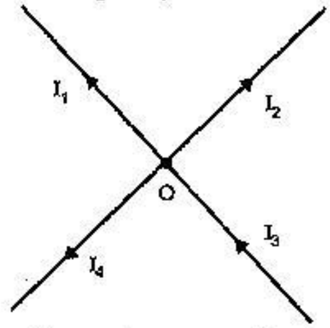


**Answers is not given due to change in the present syllabus.

13. State Kirchhoff's rules. Explain briefly how these rules are justified. **[3]**

Answer : Kirchhoff's first Law–Junction Rule

In an electrical circuit, the algebraic sum of the currents meeting at a junction is always zero.



I_1, I_2, I_3 and I_4 are the currents flowing through the respective wires.

Convention : The current flowing towards the junction is taken as positive.

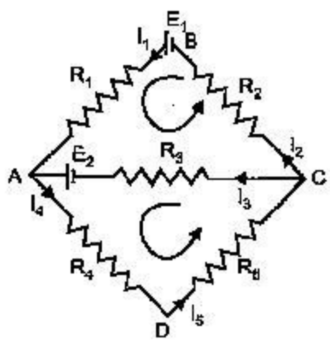
The current flowing away from the junction is taken as negative.

$$I_3 + (-I_1) + (-I_2) + (-I_4) = 0$$

This law is based on the law of conservation of charge.

Kirchhoff's Second Law – Loop rule

In a closed loop, the algebraic sum of the emf's is equal to the algebraic sum of the products of the resistances and the currents flowing through them.



For the closed loop BACB :

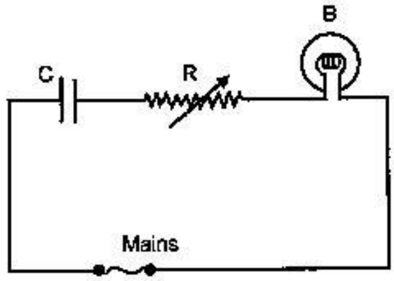
$$E_1 - E_2 = I_1R_1 + I_2R_2 - I_3R_3$$

For the closed loop CADC :

$$E_2 = I_3R_3 + I_4R_4 + I_5R_5$$

This law is based on the law of conservation of energy.

14. A capacitor 'C', a variable resistor 'R' and a bulb 'B' are connected in series to the ac mains in circuit as shown. The bulb glows with some brightness. How will the glow of the bulb change if (i) a dielectric slab is introduced between the plates of the capacitor, keeping resistance R to be the same; (ii) the resistance R is increased keeping the same capacitance ? **[3]**



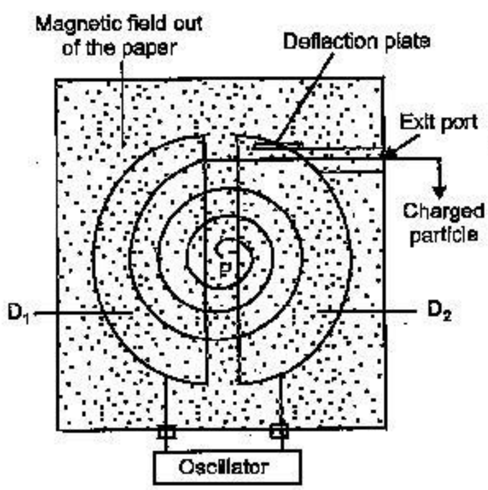
Answer : (i) As the dielectric slab is introduced between the plates of the capacitor, its capacitance will increase. Hence, the potential drop across the capacitor will decrease ($V = Q/C$). As a result, the potential drop across the bulb will increase (since both are connected in series). So, its brightness will increase.

(ii) As the resistance (R) is increased, the potential drop across the resistor will increase. As a result, the potential drop across the bulb will decrease (since both are connected in series). So, its brightness will decrease.

15. State the underlying principle of a cyclotron. Write briefly how this machine is used to accelerate charged particles to high energies. **[3]**

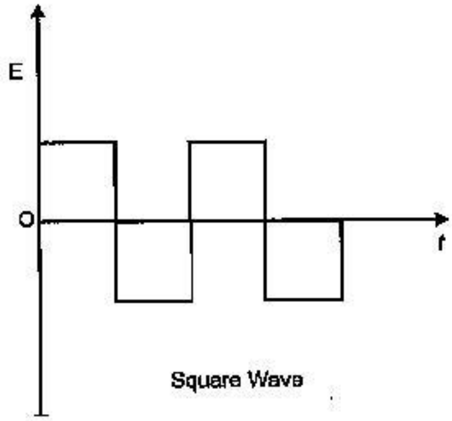
Answer : The underlying principle of a cyclotron is that an oscillating electric field can be used to accelerate a charged particle to high energy.

A cyclotron involves the use of an electric field to accelerate charge particles across the gap between the two D-shaped magnetic field regions. The magnetic field is perpendicular to the paths of the charged particles that makes them follow in circular paths within the two Ds. An alternating voltage accelerates the charged particles each time they cross the Ds. The radius of each particle's path increases with its speed. So, the accelerated particles spiral toward the outer wall of the cyclotron.



The Ds are the semi-circular structures (D_1 and D_2) between which the charges move. The accelerating voltage is maintained across the opposite halves of the Ds.

Square wave electric fields are used to accelerate the charged particles in a cyclotron.



The accelerating electric field reverses just at the time the change particle finishes its half circle. So that it gets accelerated across the gap between the Ds.

The particle gets accelerated again and again, and its velocity increases. Therefore, it attains high kinetic energy.

The positively charged ion adopts a circular path with a constant speed v, under the action of magnetic field B, which is perpendicular to the planes of D's of radius r.

$$r = \frac{mv}{qB}$$

16. An electric dipole of length 4 cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $4\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has charge ± 8 nC. **[3]**

Answer : As $\tau = pE \sin\theta$

$\therefore$ $4\sqrt{3} = pE \sin\theta$

$\Rightarrow$ $pE \times \frac{\sqrt{3}}{2} = 4\sqrt{3}$

$\Rightarrow$ $pE = 8$

Potential energy of dipole,

$$U = -pE\cos\theta$$
$$= -pE\cos 60°$$
$$= -8 \cdot \frac{1}{2}$$
$$= -4 \text{ J}.$$

17. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has

(a) **greater value of de-Broglie wavelength associated with it, and**

(b) **less momentum ?**

Give reasons to justify your Answer. **[3]**

Answer : (a) de-Broglie wavelength,

$\lambda \propto 1/\text{mass}$ (for same accelerating potential)

Mass of a proton is less as compared to a deuteron. So, proton will have greater value of de-Broglie wavelength associated with it.

(b) Momentum, $p \propto$ mass (for same accelerating potential)

Mass of deuteron is more as compared to a proton. So, it will have a greater value of momentum.

18. (i) Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface. **[3]**

Answer: (i) The energy of a photon of frequency ν is $E = h\nu = (6.63 \times 10^{-34}\ \text{Js}) \times (6 \times 10^{14}\ \text{s}^{-1}) = 3.98 \times 10^{-19}\ \text{J} = 4\ 10^{-19}\ \text{J}$

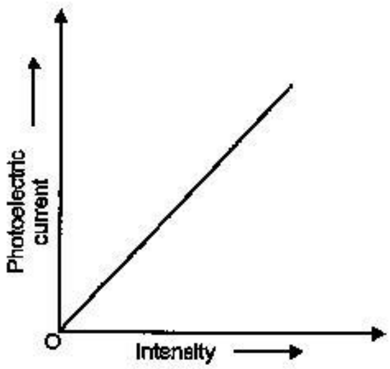
If n be the number of photons emitted by the source per second, then the power P transmitted in the beam is given by

$$P = nE$$

$$\therefore \quad n = \frac{P}{E}$$

$$\Rightarrow \quad n = \frac{2\times10^{-3}}{4\times10^{-19}} = 5 \times 10^{15}\ \text{photons/sec.}$$

(ii)



19. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited ? Calculate the wavelength of the first member of Lyman and first member of Balmer series. **[3]**

Answer : Energy of the electron in the n^{th} state of an atom

$$= \frac{-13.6}{n^2} \times Z^2 eV$$

Here, Z is the atomic number of the atom. For hydrogen atom, Z is equal to 1. Energy required to excite an atom from the initial state (n_i) to the final state (n_f).

$$E_f = \frac{-13.6}{n_f^2} + \frac{13.6}{n_i^2}\ \text{eV}$$

This energy must be equal to or less than the energy of the incident electron beam.

$$\Rightarrow \quad -\frac{-13.6}{n_f^2} + \frac{13.6}{n_i^2} = 12.5$$

Energy of the electron in the ground state = 13.612 = −13.6 eV

$$\Rightarrow \quad \frac{-13.6}{n_f^2} + 13.6 = 12.5 \qquad [\because n_i = 1]$$

$$\Rightarrow \quad 13.6 - 12.5 = \frac{13.6}{n_f^2}$$

$$\Rightarrow \quad n_f^2 = \frac{13.6}{1.1}$$

$$\Rightarrow \quad n_f^2 = 12.36$$

$$\Rightarrow \quad n_f = 3.5$$

State cannot be a fraction number $n_f = 3$

Hence, hydrogen atom would be excited up to 3rd energy level.

Rydberg formula for the spectrum of the hydrogen atom is given below.

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Here, λ is the wavelength and R is the Rydberg constant.

$$R = 1.097 \times 10^7\ \text{m}^{-1}$$

For the first member of the Lyman series : $n_f = 1$ and $n_i = 2$

$$\frac{1}{\lambda} = 1.097\times10^7\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

$$\lambda = 1215\ (\text{Å})$$

For the first member of Balmer series : $n_f = 2$ and $n_i = 3$

$$\frac{1}{\lambda} = 1.097\times10^7\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\Rightarrow \quad \lambda = 6563\ \text{Å}$$

20. When Sunita, a class XII student, came to know that her parents are planning to rent out the top floor of their house to a mobile company she protested. She tried hard to convince her parents

that this move would be a health hazard.

Ultimately her parents agreed : [3]

(1) In what way can the setting up of transmission tower by a mobile company in a residential colony prove to be injurious to health ?

(2) By objecting to this move of her parents, what value did Sunita display ?**

(3) Estimate the range of e.m. waves which can be transmitted by an antenna of height 20 m. (Given radius of the earth = 6400 km) [3]

Answer : (1) A transmitting tower makes use of electromagnetic waves such as microwaves, exposure to which can cause severe health hazards like, giddiness, headache, tumour and cancer. Also, the transmitting antenna operates on a very high power, so the risk of someone getting severely burnt in a residential area increases.

(3) Range of the transmitting antenna.

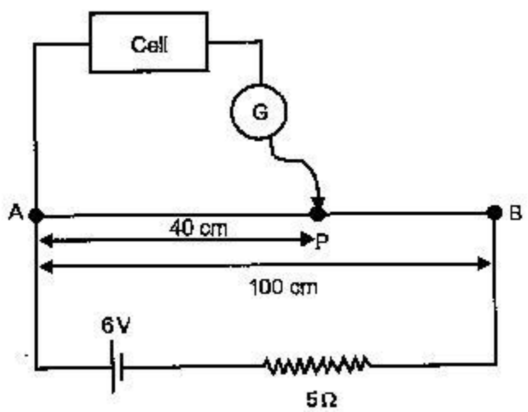
$$d = \sqrt{2hR}$$

Here, h is the height of the transmitting antenna and R is the radius of the earth.

$$R = 6400 \text{ km}$$
$$= 64 \times 10^5 \text{ m}$$
$$d = \sqrt{2 \times 20 \times 64 \times 10^5}$$
$$= 16000 \text{ m}$$

21. A potentiometer wire of length 1 m has a resistance of 10 Ω. It is connected to a 6 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm. [3]

Answer : From the figure below :



Total resistance of the circuit,

$$R = (R_{AB} + 5) = (10 + 5)\ \Omega = 15\ \Omega$$

Current in the circuit, $I = \frac{V}{R} = \frac{6}{15} A$

$$V_{AB} = 6 - \frac{6}{15} \times 5$$
$$= 6 - 2 = 4 \text{ V}$$

∴ Voltage across AB,

Emf of the cell, $e = \left(\frac{l}{L}\right) V_{AB}$

Here : $l = 40$ m (balance point)

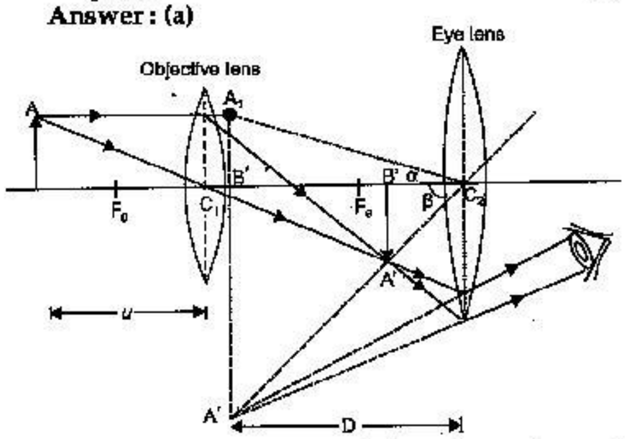
AB = L = 1 m = 100 cm (total length of the wire)

$$\therefore \quad e = \left(\frac{40}{100}\right) 4 = 1.6\text{V}$$

22. (a) Draw a labelled ray diagram showing the formation of a final image by a compound microscope at least distance of distinct vision.

(b) The total magnification produced by a compound microscope is 20. The magnification produced by the eye piece is 5. The microscope is focussed on a certain object. The distance between the objective and eye-piece is observed to be 14 cm. If least distance of distinct vision is 20 cm, calculate the focal length of the objective and the eye-piece. [3]

Answer : (a)



(b) For the least distance of clear vision, the total magnification is given by :

$$m = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right) = m_o m_e \qquad \text{...(i)}$$

where,

L is the separation between the eyepiece and the objective

f_o is the focal length of the objective

f_e is the focal length of the eyepiece.

D is the least distance for clear vision.

Also, the given magnification for the eyepiece :

$$m_e = 5 \; m_e = 1 + \frac{D}{f_e}$$

**Answers is not given due to change in the present syllabus.

$\Rightarrow \quad 5 = 1 + \frac{20}{f_e}$

$\Rightarrow \quad f_e = 5$ cm

Substituting the value of m and m_e in equation (i), we get :

$$m = m_o m_e$$
$$20 = m_o \times 5$$
$$m_o = 4$$

For the eyepiece $v_e = -20$cm, fe = 5cm

$$\therefore u_e = \frac{v_e f_e}{f_e - v_e} = \frac{20 \times 5}{5 + 20} = -4\text{cm}$$

Now, we have

$$|u_e| + |v_o| = 14$$

(*i. e.*, distance between objective and eye piece)

$$u_e + v_o = 14$$
$$v_o = (14 - 4) \text{ cm}$$

$\Rightarrow \quad v_o = 10$ cm

Now, $\quad m_o = 1 - \frac{v_o}{f_o}$

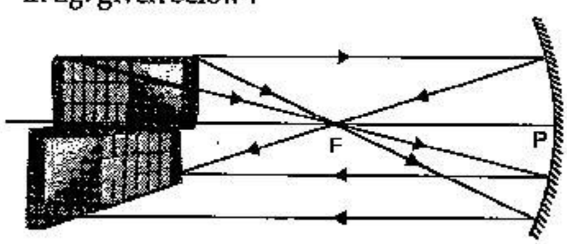
$\Rightarrow \quad -4 = 1 - \frac{10}{f_o}$

$$f_o = 2 \text{ cm}$$

23. (a) A mobile phone lies along the principal axis of a concave mirror. Show, with the help of a suitable diagram, the formation of its image. Explain why magnification is not uniform.

(b) Suppose the lower half of the concave mirror's reflecting surface is covered with an opaque material. What effect this will have on the image of the object ? Explain. [4]

Answer : (a) The image of the mobile phone formed by the convave mirror will be as shown in fig. given below :



The magnification produced by a concave mirror,

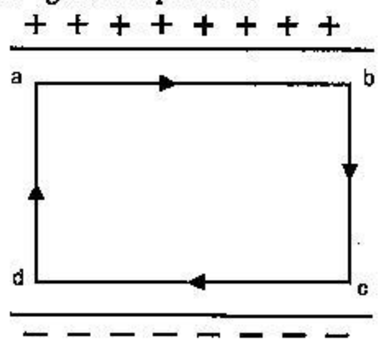
$$m = \frac{I}{O} = \frac{f}{f - u}$$

Since the object distance for the different parts of the mobile phone along its length are different, the different parts will be magnified differently. Hence, the magnification is not uniform.

(b) As the laws of reflection are true for all points of the mirror, the height of the whole image will be produced. However, as the area of the reflecting surface has been reduced, the image intensity will be reduced. In other words, the image produced will be less bright.

24. (a) Obtain the expression for the energy stored per unit volume in a charged parallel plate capacitor.

(b) The electric field inside a parallel plate capacitor is E. Find the amount of work done in moving a charge q over a closed rectangular loop $abcda$. [5]



OR

(a) Derive the expression for the capacitance of a parallel plate capacitor having plate area A and plate separation d.

(b) Two charged spherical conductors of radii R_1 and R_2 when connected by a conducting wire acquire charge q_1 and q_2 respectively. Find the ratio of their surface charge densities in terms of their radii.

Answer : (a) Let us consider a parallel-plate capacitor of plate area A. If separation between plates is d metre, capacitance C is given by

$$C = \frac{\varepsilon_0 A}{d}$$

We know that, the magnitude of the electric field between the charged plates of the capacitor is

$$E = \frac{\sigma}{\varepsilon_0}$$

Where σ in surface density of either plate. Therefore, the plate charge is

$$Q = \sigma A = \varepsilon_0 EA$$

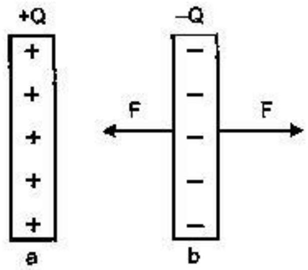
Now, the energy stored in the capacitor is

$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}\frac{(\varepsilon_0 EA)^2}{\varepsilon_0 A/d}$$

$$U = \frac{1}{2}\varepsilon_0 E^2 (Ad) \text{ J}$$

The volume between the plates is Ad metre^3. Therefore, the energy per unit volume is given by

$$U' = \frac{U}{Ad} = \frac{1}{2}\varepsilon_0 E^2 \text{ J/m}^3$$



(b) Work done, $W = F.d$

Here, F is the force exerted on the charge (q) due to electric field (E) and is given by,

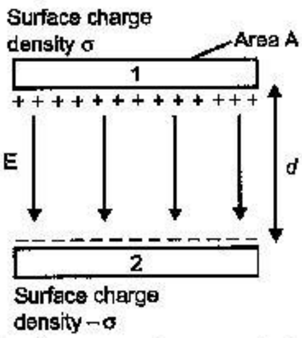
$$F = qE$$

Net displacement, $d = 0$

$$\therefore \quad W = 0$$

OR

(a) Derivation for the capacitance of parallel plate capacitor:



A parallel plate capacitor consists of two large plane parallel conducting plates separated by a small distance. The two plates have charges q and $-q$ and distance between them is d.

Plate 1 has charge density, $\sigma = \dfrac{q}{A}$

Plate 2 has charge density, $\sigma = -\dfrac{q}{A}$

In the inner region between the plates 1 and 2, the electric fields due to the two charged plates add up.

$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0} = \frac{q}{A\varepsilon_0}$$

The direction of electric field is from the positive to the negative plate.

For this electric field, potential difference between the plates is given by,

$$V = Ed = \frac{1}{\varepsilon_0}\frac{qd}{A}$$

The capacitance C of the parallel plate capacitor is then

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d}$$

(b) The surface charge density for a spherical conductor of radius R_1 is given by :

$$\sigma_1 = \frac{q_1}{4\pi R_1^2}$$

Similarly, for spherical conductor R_2, the surface charge density is given by :

$$\sigma_2 = \frac{q_2}{4\pi R_2^2}$$

$$\therefore \quad \frac{\sigma_1}{\sigma_2} = \frac{q_1 R_2^2}{q_2 R_1^2} \quad \text{...(i)}$$

As the spheres are connected so the charges will flow between the spherical conductors till their potential become equal.

i.e., $$\frac{kq_1}{R_1} = \frac{kq_2}{R_2}$$

$$\Rightarrow \quad \frac{q_1}{q_2} = \frac{R_1}{R_2} \quad \text{...(ii)}$$

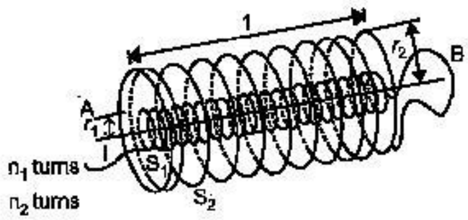
Using (ii) in (i)

We have, $$\frac{\sigma_1}{\sigma_2} = \frac{R_1}{R_2}\cdot\frac{R_2^2}{R_1^2} = \frac{R_2}{R_1}$$

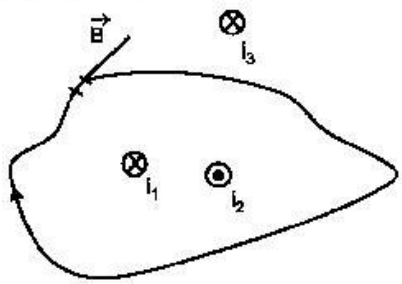
$$\Rightarrow \quad \frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$$

25. (a) State Ampere's circuital law, expressing it in the integral form.

(b) Two long coaxial insulated solenoids, S_1 and S_2 of equal lengths are wound one over the other as shown in the figure. A steady current "I" flow through the inner solenoid S_1 to the other end B, which is connected to the outer solenoid S_2 through which the same current "I" flows in the opposite direction so as to come out at end A. If n_1 and n_2 are the number of turns per unit length, find the magnitude and direction of the net magnetic field at a point (i) inside on the axis and (ii) outside the combined system. **[5]**



Answer: (a) Ampere's circuital law states that the circulation of the resultant magnetic field along a closed, plane curve is equal to μ_0 times the total current crossing the area bounded by the closed curve, provided the electric field inside the loop remains constant.



In the above illustration, the Ampere's circuital law can be written as follows :

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i$$

where $i = i_1 - i_2$

(b) (i) The magnetic field due to a current carrying solenoid :

$$B = \mu_0 ni$$

where, n = number of turns per unit length, i = current through the solenoid.

Now, the magnetic field due to solenoid S_1 will be in the upward direction and the magnetic field due to S_2 will be in the downward direction (by right-hand screw rule).

$$B_{net} = B_1 - B_2$$

$$B_{net} = \mu_0 n_1 I - \mu_0 n_2 I$$

$$= \mu_0 I(n_1 - n_2)$$

(ii) The magnetic field is zero outside a solenoid.

26. Answer the following : **[5]**

(a) Name the e.m. waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.

(b) If the earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now ? Explain.

(c) An e.m. wave exerts pressure on the surface on which it is incident. Justify.

Answer : (a) Microwaves are suitable for radar systems used in aircrafts navigation. The range of frequency for these waves is 10^9 Hz to 10^{12} Hz.

(b) In the absence of atmosphere, there would be no greenhouse effect on the surface of the Earth. As a result, the temperature of the Earth would decrease rapidly, making it difficult for human survival.

(c) The momentum transported by electromagnetic waves is given by

$$p = \frac{U}{c}$$

where U is the energy transported by electromagnetic waves in a given time and c is speed of electromagnetic waves in free space. As a result, when these waves strike a surface, pressure and hence force is exerted by them on the surface.

27. (a) Deduce the expression, $N = N_0 e^{-\lambda t}$, for the law of radioactive decay.

(b) (i) Write symbolically the process expressing the β+ decay of $^{22}_{11}Na$. Also write the basic nuclear process underlying this decay.

(ii) Is the nucleus formed in the decay of the nucleus $^{22}_{11}Na$, an isotope or isobar? **[5]**

Answer : (a) Suppose initially the number of atoms in radioactive element is N_0 and N the number of atoms after time t. After time t, let dN be the number of atoms which disintegrate in a short interval dt, then rate of disintegration will be, $\frac{dN}{dt}$, this is also called the activity of the element.

According to Rutherford-Soddy law,

$$\frac{dN}{dt} \propto N$$

or $$\frac{dN}{dt} = -\lambda N \quad ...(i)$$

where λ is a constant, called decay constant or disintegration constant of the element. Its unit is s^{-1}. Negative sign shows that the rate of disintegration decreases with increase of time. For a given element λ is a constant and is different for different elements. Equation (i) may be rewritten as

$$\frac{dN}{N} = -\lambda dt$$

Integrating $\log_e N = -\lambda t + C$ ...(ii)

where C is a constant of integration.

At $t = 0, N = N_0$

$\therefore$ $\log_e N_0 = 0 + C \Rightarrow C = \log_e N_0$

$\therefore$ Equation (ii) gives $\log_e N = -\lambda t + \log_e N_0$

or $$\log_e N - \log_e N_0 = -\lambda t$$

or $$\log_e \frac{N}{N_0} = -\lambda t$$

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$N = N_0 e^{-\lambda t}$$

(b) (i) The β^+ decay of $_{11}N^{22}$ is expressed as below :

$$_{11}N^{22} \rightarrow {}_{10}Ne^{22} + 1e^0 + \nu$$

The neutron-proton ratio is also an important factor that determines the stability of a nucleus. A proton-rich nucleus undergoes positron emission (β^+ decay), so as to improve the neutron-proton ratio. The positron emission decreases proton number relative to neutron number and the product nucleus becomes relatively more stable. In β^+ decay, neutrino (ν) is emitted so as to conserve spin.

(ii) The nucleus so formed is an isobar of $11N^{22}_a$ because the mass number is same, but the atomic numbers are different.

28. (a) (i) 'Two independent mono-chromatic sources of light cannot produce a sustained interference pattern'. Give reason.

(ii) Light wave each of amplitude 'a' and

frequency 'ω', emanating from two coherent light sources superpose at a point. If the displacements due to these waves is given by $y_1 = a \cos \omega t$ and $y_2 = a \cos(\omega t + \phi)$ where ϕ is the phase difference between the two, obtain the expression for the resultant intensity at the point.

(b) In Young's double slit experiment, using monochromatic light of wavelength λ, the intensity of light at a point on the screen where path difference is λ, is K units. Find out the intensity of light at a point where path difference is λ/3. [5]

OR

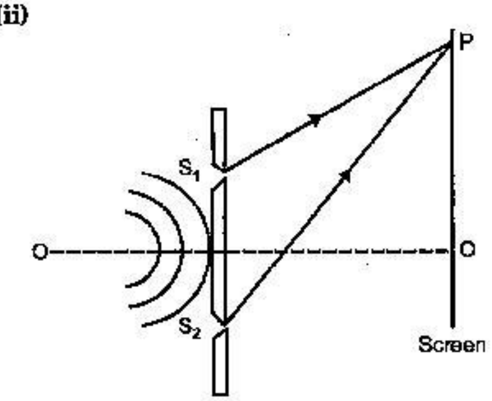
(a) How does one demonstrate, using a suitable diagram, that unpolarised light when passed through a polaroid gets polarized ?

(b) A beam of unpolarised light is incident on a glass-air interface. Show, using a suitable ray diagram, that light reflected from the interface is totally polarised, when $\mu = \tan i_B$, where μ is the refractive index of glass with respect to air and i_B is the Brewster's angle.

Answer : (a) (i) The condition for the sustained interference is that both the sources must be coherent (*i.e.,* they must have the same wavelength and the same frequency, and they must have the same phase or constant phase difference).

Two sources are monochromatic if they have the same frequency and wavelength. Since they are independent, *i.e.,* they have different phases with irregular difference, they are not coherent sources.

(ii)



Let the displacement of the waves from the sources S_1 and S_2 at point P on the screen at any time t be given by :

$$y_1 = a \cos \omega t$$

and $$y_2 = a \cos(\omega t + \phi)$$

Where, ϕ is the constant phase difference between the two waves.

By the superposition principle, the resultant displacement at point P is given by :

$$y = y_1 + y_2$$

$$y = a \cos \omega t + a \cos(\omega t + \phi)$$

$$y = 2a\left[\cos\left(\frac{\omega t + \omega t + \phi}{2}\right)\cos\left(\frac{\omega t - \omega t - \phi}{2}\right)\right]$$

$$y = 2a \cos\left(\omega t + \frac{o}{2}\right)\cos\left(\frac{\phi}{2}\right) \quad ...(i)$$

Let $2a \cos(o/2) = A$ ...(ii)

Then, equation (i) becomes

$$y = A \cos(\omega t + \phi/2)$$

Now, we have :

$$A^2 = 4a^2 \cos^2(\phi/2) \quad ...(iii)$$

The intensity of light is directly proportional to the square of the amplitude of the wave. The intensity of light at point on the screen is given by

$$I = 4a^2 \cos^2 \frac{\phi}{2}$$

(b) Intensity $I = 4I_0 \cos^2 \frac{\phi}{2}$

When path difference is λ, phase difference is 2π

$$I = 4I_0 \cos^2 \pi$$
$$= 4I_0 = k \text{ (given)}$$

When path difference, $\Delta = \frac{\lambda}{3}$, the phase difference

$$\phi_1 = \frac{2\pi}{\lambda}\Delta$$

$$= \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$$

$$I_1 = 4I_0 . \cos^2 \frac{2\pi}{3} \quad \text{(since } k = 4I_0\text{)}$$

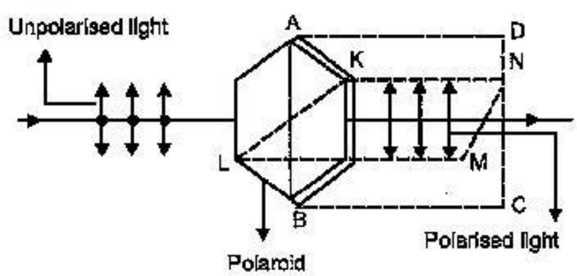
$$= k \cos^2 \frac{2\pi}{3}$$

$$= k \times \left(-\frac{1}{2}\right)^2$$

$$= \frac{1}{4}k$$

OR

(a)



The phenomenon of restricting the vibration of light (electric vector) in a particular direction perpendicular to the direction of the wave propagation is called polarization of light.

When unpolarised light is passed through a polaroid, only those vibrations of light pass through the crystal, which are parallel to the axis of the crystal (AB). All other vibrations are absorbed and that is why intensity of the emerging light is reduced.

The plane ABCD in which the vibrations of the polarised light are confined is called the plane of vibration. The plane KLMN that is perpendicular to the plane of vibration is defined as the plane of polarization.

(b) When unpolarised light is incident on the glass-air interference at Brewster angle i_B, then reflected light is totally polarised. This is called Brewster's Law.

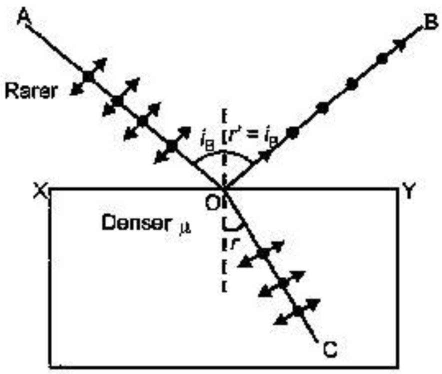
When light is incident at Brewster angle, the reflected component OB and the refracted component OC are mutually perpendicular to each other.

From the figure,

We have : $\angle BOY + \angle YOC = 90^\circ$

$$(90^\circ - i_B) + (90^\circ - r) = 90^\circ$$

$$i_B + \mu = 90^\circ$$



Where, r is angle of refraction

According to the Snell's law :

$$\mu = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{\sin(90^\circ - i_B)}$$

$$\mu = \frac{\sin i_B}{\cos i_B}$$

$\mu = \tan i_B$ **Hence proved.**

29. (a) Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce a current which opposes the change of magnetic flux that produces it.

(b) The current flowing through an inductor of self inductance L is continuously increasing. Plot a graph showing the variation.

(i) Magnetic flux versus the current

(ii) Induced emf versus dI/dt

(iii) Magnetic potential energy stored versus the current. **[5]**

OR

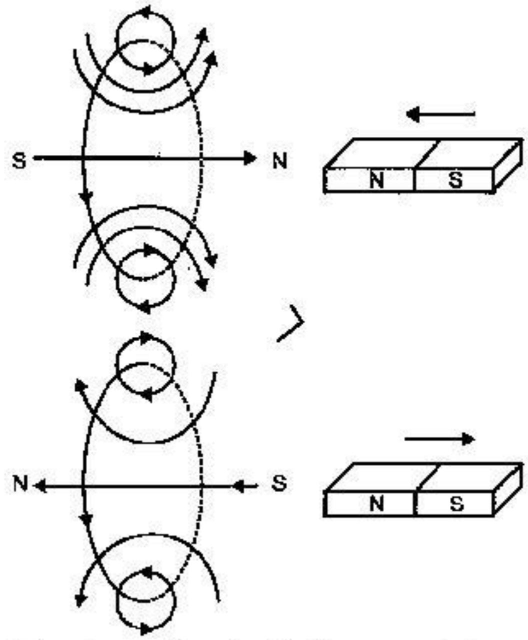
(a) Draw a schematic sketch of an ac generator describing its basic elements. State briefly its working principle. Show a plot of variation of

(i) Magnetic flux and

(ii) Alternating emf versus time generated by a loop of wire rotating in a magnetic field.

(b) Why is choke coil needed in the use of fluorescent tubes with ac mains ?

Answer : (a) Lenz's law : According to Lenz's law, the polarity of the induced emf is such that it opposes a change in magnetic flux responsible for its production.



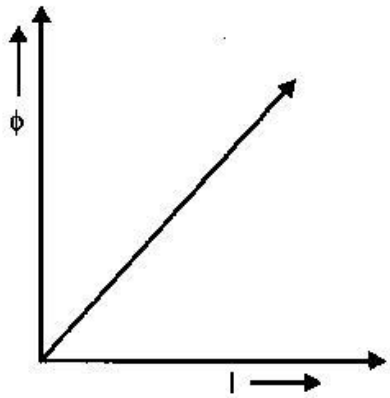
When the north pole of a bar magnet is pushed towards the coil, the amount of magnetic flux linked with the coil increase. Current is reduced in the coil from a direction such that it opposes the increase in magnetic flux. This is possible only when the current induced in the coil is in anti-clockwise direction, with respect to an observer. The magnetic moment M associated with this induced emf has north polarity, towards the north pole of the approaching bar magnet. Similarly, when the north pole of the bar magnet is moved away from the coil, the magnetic flux linked with the coil decreases. To counter this decrease in magnetic flux, current is induced in the coil in clockwise direction so that its south pole faces the receding north pole of the bar magnet. This would result in an attractive force which opposes the motion of the magnet and the corresponding decrease in magnetic flux.

(b) (i) Since $\phi = LI$

where, I = strength of current through the coil at any time

ϕ = Amount of magnetic flux linked with all turns of the coil at that time and,

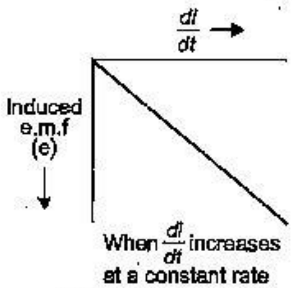
L = Constant of proportionally called coefficient of self induction.

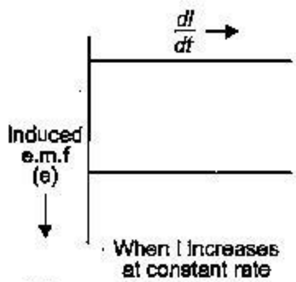


(ii) Induced emf,

$$e = \frac{-d\phi}{dt} = -\frac{d(LI)}{dt}$$

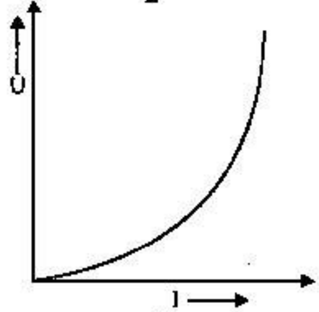
i.e. $$e = -L\left(\frac{dI}{dt}\right)$$





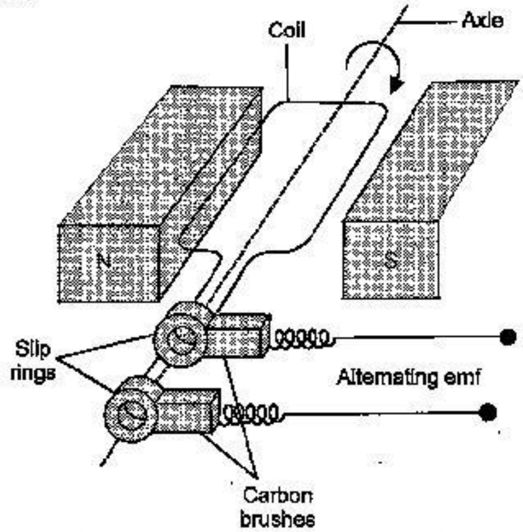
(iii) Since magnetic potential energy is given by

$$U = \frac{1}{2}LI^2$$



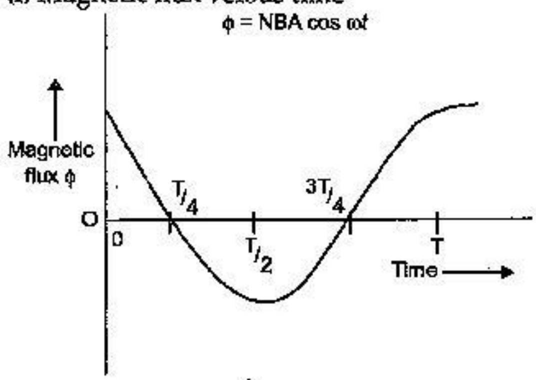
OR

(a)



It works on the process of electromagnetic induction, *i.e.*, when a coil rotates continuously in a magnetic field, the effective area of the coil, linked (normally) with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of a (alternating) emf in the coil.

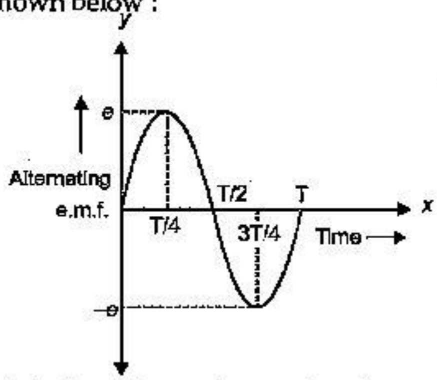
(i) Magnetic flux versus time



(ii) Alternating emf versus time

$e = NAB\omega \sin \omega t = e_0 \sin \omega t$

The graph between alternating emf versus time is shown below :



(b) A choke coil is an electrical appliance used for controlling current in an a.c. circuit. Therefore, if we use a resistance R for the same purpose, a lot of energy would be wasted in the form of heat etc.

30. (a) State briefly the processes involved in the formation of *p-n* junction explaining clearly how the depletion region is formed.

(b) Using the necessary circuit diagram, show how the V-I characteristics of a *p-n* junction are obtained in

(i) Forward biasing

(ii) Reverse biasing

How are these characteristics made use of in rectification ? [5]

OR

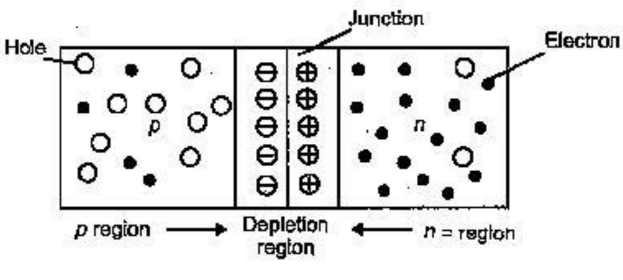
(a) Differentiate between three segments of a transistor on the basis of their size and level of doping.**

(b) How is a transistor biased to be in active state ?**

(c) With the help of necessary circuit diagram, describe briefly how *n-p-n* transistor in CE configuration amplifies a small sinusoidal input voltage. Write the expression for the ac current gain.**

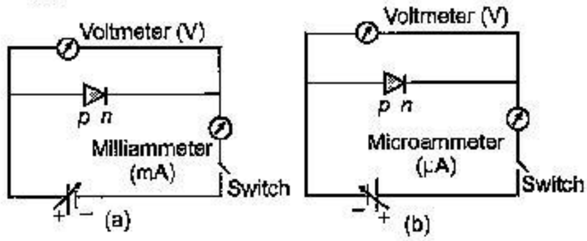
Answer : (a) As we know that *n*-type semi-conductor has more concentration of electrons than that of a hole and *p*-type semi-conductor has more concentration of holes than an electron. Due to the difference in concentration of charge carriers in the two regions of *p-n* junction, the holes diffuse from *p*-side to *n*-side and electrons diffuse from *n*-side to *p*-side.

When an electron diffuses from *n* to *p*, it leaves behind an ionized donor on *n*-side. The ionised donor (+*ve* charge) is immobile as it is bounded by the surrounding atoms. Therefore, a layer of positive charge is developed on the *n*-side of the junction. Similarly, a layer of negative charge is developed on the *p*-side.

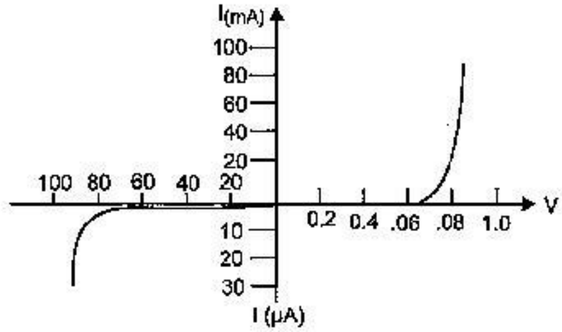


Hence, a space-charge region is formed on both side of the junction, which has immobile ions and is devoid of any charge carrier, called as depletion layer or depletion region.

(b)



Using the circuit arrangements shown in fig (a) and fig (b), we study the variation of current with applied voltage to obtain the V-I characteristics shown below.



(c)

From the V-I characteristics of a junction diode, it is clear that it allows the current to pass only when it is forward biased. So when an alternating voltage is applied across the diode, current flows only during that part of the cycle when it is forward biased.

Physics 2014 (Delhi) SET II

Time allowed : 3 hours **Maximum marks : 70**

Note : Except for the following questions, all the remaining questions have been asked in previous Set.

1. Define the term 'electrical conductivity' of a metallic wire. Write its S.I. unit. [1]

Answer : The electrical conductivity of a metallic wire is defined as the ratio of the current density to the electric field it creates.

Electrical conductivity, $\sigma = \frac{J}{E}$

**Answers is not given due to change in the present syllabus.

S.I. unit = $(\text{ohm m})^{-1}$

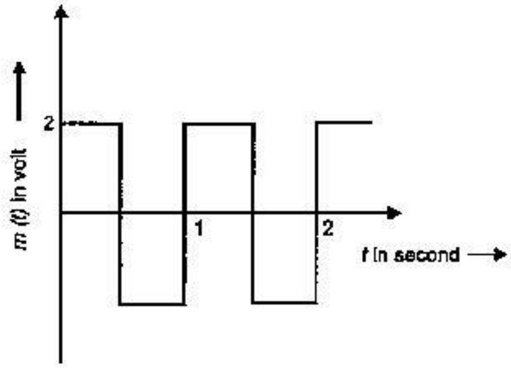
OR

The reciprocal of resistivity of a material is called its electrical conductivity.

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

or $$\sigma = \frac{1}{\rho}$$

2. The carrier wave is represented by C (*t*) = 5 sin (10 π*t*) volt A modulating signal is a square wave as shown. Determine modulation index.** **[1]**



10. An electric dipole of length 2 cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $8\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has a charge of ±4 nC. **[2]**

Answer : As $\tau = pE \sin\theta$

$$\therefore \quad 8\sqrt{3} = pE \sin\theta$$

$$= pE \sin 60^\circ$$

$$= \frac{pE\sqrt{3}}{2}$$

$$\Rightarrow \quad pE = 16$$

Also potential energy of the dipole,

$$\Rightarrow \quad U = -pE\cos\theta$$

$$= -pE\cos 60^\circ$$

$$= \frac{-16 \cdot 1}{2} = -8 \text{ J}.$$

15. A proton and an alpha particle are accelerated through the same potential ? Which one of the two has (i) greater value of de-Broglie wavelength associated with it and (ii) less kinetic energy. Give reasons to justify your answer. **[3]**

Answer : (i) de-Broglie wavelength of a particle depends upon its mass and charge for same accelerating potential such that

$$\lambda \propto \frac{1}{\sqrt{(\text{Mass})(\text{Charge})}}$$

If mass and charge of a proton are m_p and e respectively, then, mass and charge of an alpha particle are $4m_p$ and $2e$ respectively. Where, e is the charge of an electron

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p\, q_p}}$$

$$= \sqrt{\frac{(4m_p)(2e)}{(m_p)(e)}} = 2\sqrt{2}$$

Thus, de-Broglie wavelength associated with proton is $2\sqrt{2}$ times of the de-Broglie wavelength of alpha particle.

(ii) K.E. ∝ q (for same accelerating potential).

Charge of an alpha particle is more as compared to a proton. So, it will have a greater value of K.E. Hence, proton will have lesser kinetic energy.

16. Given a uniform electric field $\vec{E} = 2 \times 10^3\,\hat{i}$ N/C. Find the flux of this field through a square of side 20 cm, whose plane is parallel to the Y-Z plane. What would be the flux through the same square, if the plane makes an angle of 30° with the X-axis ? **[3]**

Answer : When the plane is parallel to the Y-Z plane

$$\phi = \vec{E}\cdot\vec{A}$$

Here,

$$\vec{E} = 2\times 10^3\,\hat{i}$$

$$A = (20\text{ cm})^2 i = 0.04\text{ m}^2 i.$$

$$\therefore \quad \phi = (2\times 10^3 i).(0.04 i).$$

$$\Rightarrow \quad \phi = 80 \text{ weber or Nm}^2\text{C}^{-1}.$$

When the plane makes a 30° angle with the X-axis, the area vector makes a 60° angle with the X-axis.

$$\phi = \vec{E}\cdot\vec{A}$$

$$\Rightarrow \quad \phi = EA\cos\theta$$

$$\Rightarrow \quad \phi = 2\times 10^3 \times 0.04 \times \cos 60^\circ$$

$$\Rightarrow \quad \phi = 2\times 10^3 \times 0.04 \times \frac{1}{2}$$

$$\Rightarrow \quad \phi = 40 \text{ weber or Nm}^2\text{C}^{-1}.$$

20. A 12.9 eV beam of electronic is used to bombard gaseous hydrogen at room temperature.

Upto which energy level the hydrogen atoms would be excited ? Calculate the wavelength

**Answers is not given due to change in the present syllabus.

of the first member of Paschen series and first member of Balmer series. **[3]**

Answer : Energy of the electron in the n^{th} state of an atom

$$= \frac{-13.6Z^2}{n^2}$$

Here, Z is the atomic number of the atom.

For hydrogen atom, Z = 1

Energy required to excite an atom from initial state (n_i) to final state (n_f),

$$E = -13.6\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)\text{eV}$$

$$\Rightarrow \quad \frac{-13.6}{n_f^2} + \frac{13.6}{n_i^2} = 12.9$$

This energy must be equal to or less than the energy of the incident electron beam.

$$\Rightarrow 13.6 - 12.9 = \frac{13.6}{n_f^2}. \qquad [\because n' = 1]$$

$$n_f^2 = \frac{13.60}{0.7} = 19.43.$$

$$\Rightarrow \quad n_f = 4.4.$$

State cannot be a fraction number.

$$\Rightarrow \quad n_f = 4.$$

Hence, the hydrogen atom would be excited up to 4^{th} energy level.

Rydberg's formula for the spectrum of the hydrogen atom is given by :

$$\frac{1}{\lambda} = R\left(\frac{1}{n_2^1} - \frac{1}{n_2^2}\right)$$

Here, λ is the wavelength.

Rydberg's constant, $R = 1.097 \times 10^7 \text{ m}^{-1}$

For the first member of the Paschen series

$$n_1 = 3, n_2 = 4$$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{3^2} - \frac{1}{4^2}\right)$$

$$\lambda = 18752.4 \text{ Å}$$

For the first member of Balmer series

$$n_1 = 2, n_2 = 3$$

$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\lambda = 6563.3 \text{ Å}$$

22. Answer the following : **[3]**

(a) Name the e.m. waves which are used for the treatment of certain forms of cancer. Write their frequency range.

(b) Thin ozone layer on top of stratosphere is crucial for human survival. Why ?

(c) Why is the amount of the momentum transferred by the e.m. waves incident on the surface so small ?

Answer : (a) Gamma rays are used for the treatment of certain forms of cancer. Their frequency range is 3×10^{19} H_3 to 5×10^{20} Hz.

(b) The thin ozone layer on top of stratosphere absorb most of the harmful ultraviolet rays coming from the Sun towards the Earth. They include UVA, UVB and UVC radiations, which can destroy the life system on the Earth. Hence, this layer is crucial for human survival.

(c) The momentum transported by electromagnetic waves is given by

$$p = \frac{U}{c} = \frac{hv}{c}$$

where U is the energy transported by electromagnetic waves in a given time and c is speed of electromagnetic waves in free space.

Now, $h = 6.62 \times 10^{-34}$ J s, $c = 3 \times 10^8$ m s^{-1}

Therefore, even for γ-rays ($v \approx 10^{20}$ Hz),

$$p = \frac{6.62 \times 10^{-34} \times 10^{20}}{3 \times 10^8}$$

$$= 2.2 \times 10^{-22} \text{ kg m s}^{-1}$$

Thus, the amount of the momentum transferred by the e.m. waves incident on a surface is very small.

24. A potentiometer wire of length 1.0 m has a resistance of 15 Ω. It is connected to a 5 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm. **[5]**

Answer : Current through potentiometer wire,

$$I = \frac{V}{R_{AB} + R}$$

$$= \frac{5}{15 + 5} 0.25 \text{ A}$$

P.D. across the potentiometer wire,

$$V = IR_{AB}$$

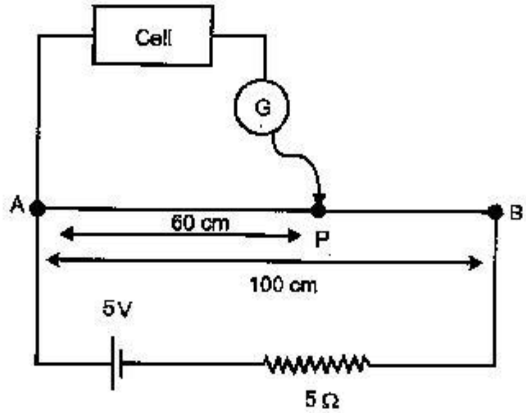
$$= 0.25 \times 15 = 3.75 \text{ V}$$

Potential gradient,

$$k = V/l$$
$$= 3.75/100$$
$$= 0.0375 \text{ V/cm}$$

So, unknown e.m.f. balanced against 60 cm of the wire,

$$e = kl' = 0.0375 \times 60$$
$$= 2.25 \text{ V}$$



Physics 2014 (Delhi)

SET III

Time allowed : 3 hours **Maximum marks : 70**

> **Note : Except for the following questions, all the remaining questions have been asked in previous Sets.**

1. **Define the term 'drift velocity' of charge carriers in a conductor and write its relationship with the current flowing through it.** **[1]**

Answer : The net speed achieved by an electron in a current carrying conductor is called as drift velocity.

The average velocity acquired by the free electrons along the length of a metallic conductor under a potential difference applied across the conductor is called drift velocity of the electrons.

$$v_d = \frac{I}{ne\,A}$$

Here :

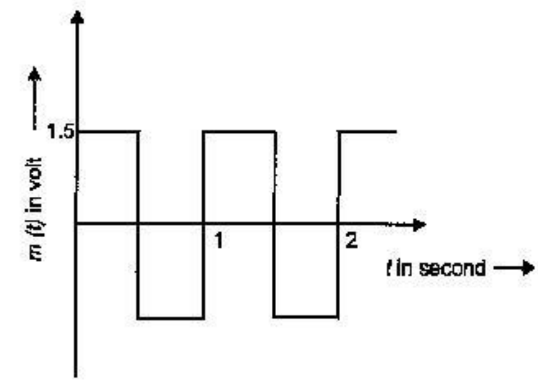
I is the current flowing through the conductor.

n is the number density of an electron.

A is the area of the conductor,

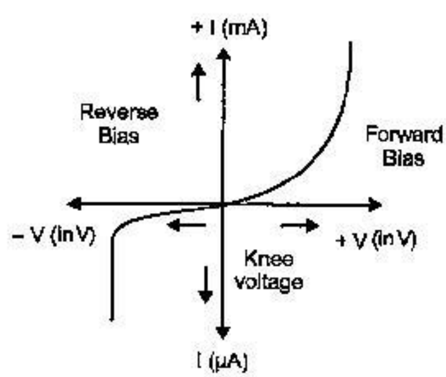
e is the charge of the electron.

2. **The carrier wave of a signal is given by $C(t) = 3 \sin (8\pi t)$ volt. The modulating signal is a square wave as shown. Find its modulation index.**** **[1]**



4. **Plot a graph showing variation of current versus voltage for the material Ga.** **[1]**

Answer : Current–Voltage characteristics graph for Ga :



9. **An electric dipole of length 2 cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $6\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has a charge of ±2 nC.** **[1]**

Answer : As $\tau = pE \sin\theta$

**Answers is not given due to change in the present syllabus.

$$6\sqrt{3} = pE \sin 60°$$

$$= pE \times \frac{\sqrt{3}}{2}$$

or $$pE = 12$$

Potential energy of a dipole,

$$U = -pE \cos \theta$$

$$= -12 \times \cos 60°$$

$$= -12 \times \frac{1}{2} = -6 \text{ J}$$

12. A deuteron and an alpha particle are accelerated with the same accelerating potential. [3]
Which one of the two has
(1) greater value of de-Broglie wavelength, associated with it, and
(2) less kinetic energy ? Explain.

Answer : (1) de-Broglie wavelength of a particle is dependent on its mass and charge for same accelerating potential, such that

$$\lambda \propto \frac{1}{\sqrt{(\text{Mass})(\text{Charge})}}$$

Mass and charge of a deuteron are $2m_p$ and e respectively and, mass and charge of an alpha particle are $4m_p$ and $2e$ respectively.
Where,

m_p = the mass of a proton.

and e = the charge of an electron.

$$\frac{\lambda_D}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_D q_D}} = \sqrt{\frac{(4m_p)(2e)}{(2m_p)(e)}} = \frac{2}{1}.$$

Thus, de-Broglie wavelength related with deuteron is twice of the de-Broglie wavelength of alpha particle.

(2) $$\text{K.E.} \propto q$$

(for same accelerating potential)

Charge of a deuteron is less as compared to an alpha particle. So, deuteron will have less kinetic energy.

15. Given a uniform electric field $\vec{E} = 4 \times 10^3 \hat{i}$ N/C. Find the flux of this field through a square of 5 cm on a side whose plane is parallel to the Y-Z plane. What would be the flux through the same square, if the plane makes an angle of 30° with the X-axis ? [3]

Answer : When the plane is parallel to the Y-Z plane :

Electric flux, $\phi = \vec{E} \cdot \vec{A}$

Here,

$$\vec{E} = 4 \times 10^3 \hat{i} \text{ N/C}$$

$$\vec{A} = (5 \text{ cm})^2 \hat{i} = 0.25 \times 10^{-2} \hat{i} \, m^2$$

$$\therefore \quad \phi = (4 \times 10^3 \hat{i}) \cdot (25 \times 10^{-4} \hat{i})$$

$$\Rightarrow \quad \phi = 10 \text{ weber or } Nm^2C^{-1}$$

When the plane makes a 30° angle with X-axis, the area vector makes a 60° angle with the X-axis.

$$\phi = \vec{E} \cdot \vec{A}$$

$$\Rightarrow \quad \phi = EA \cos \theta$$

$$\Rightarrow \quad \phi = (4 \times 10^3)(25 \times 10^{-4}) \cos 60°$$

$$\Rightarrow \quad \phi = 10/2$$

$$\Rightarrow \quad \phi = 5 \text{ weber or } Nm^2C^{-1}$$

20. A 12.3 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited ? Calculate the wavelength of the second member of Lyman series and second member of Balmer series. [3]

Answer : Let the hydrogen atoms be excited to n^{th} energy level.

$$E = -13.6 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) [\because n_i = 1]$$

$$\Rightarrow \quad 12.3 = \left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

$$\Rightarrow \quad 12.3 = 13.6 - \frac{13.6}{n^2}$$

$$\Rightarrow \quad \frac{13.6}{n^2} = 13.6 - 12.3 = 1.3$$

$$\Rightarrow \quad n^2 = \frac{13.6}{1.3}$$

$$\Rightarrow \quad n \approx 3$$

The formula for calculating the wavelength of Lyman series is given below :

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

For second member of Lyman series, $n = 3$

$$\therefore \quad \frac{1}{\lambda} = R\left(1 - \frac{1}{3^2}\right)$$

$$\Rightarrow \quad \frac{1}{\lambda} = (1.09737 \times 10^7)\left(\frac{8}{9}\right)$$

$$\Rightarrow \quad \lambda = 1025.1 \text{ Å}$$

The formula for calculating the wavelength of Balmer series is given below :

$$\therefore \quad \frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{n^2}\right)$$

For second member of Balmer series :

$$n = 4$$

$$\therefore \quad \frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{4^2}\right)$$

$$\Rightarrow \quad \frac{1}{\lambda} = (1.09737 \times 10^7)\left(\frac{3}{16}\right)$$

$$\Rightarrow \quad \lambda = 4861 \text{ Å}$$

24. Answer the following : [5]

(a) Name the em waves which are used for the treatment of certain forms of cancer. Write their frequency range.

(b) Welders wear special glass goggles while working. Why ? Explain.

(c) Why are infrared waves often called as heat waves ? Give their one application.

Answer :

(a) Gamma rays are used for the treatment of certain forms of cancer. The frequency range of Gamma rays is 3×10^{19} to 5×10^{20} Hz.

(b) Welders wear special glass goggles while working so that they can protect their eyes from harmful electromagnetic radiation.

(c) Infrared waves are often called as heat waves because they induce resonance in molecules and increase internal energy in a substance.

Infrared waves are used in burglar alarms, security lights and remote controls for television and DVD players.